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ERRATA

In the article by James H. Gardner, published in No. 8, 1910, of this Journal, the following errata should be noted:

Plate I, between pages 702 and 703, belongs to the preceding paper, by Messrs. Ball and Shaler.

Plate II, between pages 742 and 743 in the paper by Mr. Robinson, belongs between pages 708 and 709.

Label for Fig. 3, p. 716, is for Fig. 7, p. 724.

Label for Fig. 4, p. 718, is for Fig. 3, p. 716.

Label for Fig. 5, p. 720, is for Fig. 4, p. 718.

Label for Fig. 6, p. 722, is for Fig. 5, p. 720.

Label for Fig. 7, p. 724, is for Fig. 6, p. 722.

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CLIMATE AND PHYSICAL CONDITIONS OF THE KEEWATIN

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Toronto

CONTENTS

INTRODUCTION

It is intended in this paper to bring together evidence which has been accumulating during recent years as to the climate and general physical conditions of the Keewatin. Most of this evidence has to do with the sedimentary rocks of this age in western and northern Ontario, and a considerable part of it has been obtained by myself and my assistants in mapping the iron ranges of the province for the Bureau of Mines of Ontario.

Not long ago the pre-Cambrian as a whole was looked on as a geological "no man's land," full of doubt and difficulty because of the obscurity of its relations. Now, however, the succession as far as the base of the Huronian has been worked out in detail in several areas of the pre-Cambrian in America; and we find that the source of these rocks and their general relations are entirely

similar to those of later, fossiliferous, series. The mystery has largely departed from them.

So far as the Huronian or Algonkian is concerned everyone admits that the rocks, both sedimentary and eruptive, were formed like those of later times. It is true that the absence of fossils in the east and their great rarity in the West is a puzzle; but all agree that the pre-Cambrian seas were not so different from later waters as to be uninhabitable, and that forces at work in the Huronian did not differ materially from those which formed the Cambrian or later rocks.

To have this brought concisely before one it is only necessary to read Van Hise and Leith's late edition of the pre-Cambrian geology in North America, a work of admirable completeness and impartiality, summing up a literature of appalling dimensions. The former chaos has then been so far set in order that we find evidence in Huronian or Algonkian times of climates not unlike those of later ages, when wind and weather, flowing rivers and beating waves, and even great ice sheets did their regular work. In northern Ontario glaciers formed bowlder clay in lat. 46°, showing no hint of the action of primeval heat, such as the usually accepted version of the Nebular Hypothesis demands.

But there is much less certainty and much less unanimity regarding pre-Huronian times. The Huronian is cut off from the underlying rocks by one of the greatest known discordances. During the interval left unrecorded in this great unconformity the previous rocks were raised into mountains, metamorphosed by the action of intrusive granite and gneiss, and then profoundly eroded. The proofs of this are to be found in the bowlders of the Huronian tillite, which include all the lower rocks in their present metamorphosed conditions; and in the hummocky plain formed from the previous mountain ranges which in many places underlies the little-disturbed Huronian.

The world was already very old and had undergone many vicissitudes before the Huronian ice sheets began their work. What light can be thrown on the vast and vague pre-Huronian time?

Many geologists have been inclined to see in the underlying "basal complex," or *Urgebirge*, portions of the earth's original

crust or its downward extension. For example, Rosenbusch in the new edition of his *Elemente der Gesteinslehre* speaks of the crystalline schists underlying all later rocks as representing, at least in part, the earth's *erste Erstarrungskruste.*[1] Like some others of the older geologists he still holds to the Nebular Hypothesis and looks on the basal complex as having been formed at the stage when the molten earth had so far cooled as to consolidate on the surface, producing plutonic rocks and crystalline schists. According to this hypothesis it was still too hot to permit the condensation of water, so that no rivers or oceans were possible.

Elaborate theories of continent- and mountain-building are still founded on this idea of the earth's progressive cooling, and it is hard for geologists brought up like the present writer on the fiery diet of a Nebular Hypothesis as an introduction to historic geology to rid their minds of so firmly imbedded a prepossession. That astronomers also are afflicted with these bad dreams is plain from certain recent popular writings on the history of Mars as compared with earth. The conviction is however growing in the minds of many geologists that even the pre-Huronian or Archaean cannot be looked on as exceptional; that the Huronian basal conglomerate means a break in time, but no break in the continuity of marine and terrestial processes; that the affairs of the world were conducted in the same way before this great interval as after it.

Evidence of various kinds in favor of this will be given in subsequent pages.

THE KEEWATIN ERUPTIVES

"The basal complex" of the western lakes region was split up many years ago by Lawson into the Laurentian granites and gneisses and the Keewatin, the latter looked on as consisting essentially of eruptives. In the original Keewatin region on Lake-of-the-Woods eruptive rocks are in great preponderance, though Lawson recognized the presence of subordinate amounts of sediments, which will be referred to later.

These eruptives are chiefly basic—now mostly transformed

[1] *Op. cit.*, 35.

into greenstones and green schists; but there are acid rocks in important amounts—quartz porphyries, felsites, etc., and their schists. In a number of places these eruptives were lava flows showing pillow and amygdaloidal structures, and often pyroclastic materials accompanied the outbreaks of lava. It is probable that most of the characteristic Keewatin eruptives were volcanic, though the squeezing and shearing they have undergone often obscure their origin as lavas or ash rocks. Undoubted plutonic rocks occur among these surface eruptives, but often they can be proved to be much later in age, since they have penetrated the other rocks and carried off fragments of them.

There are also many dikes of both basic and acid rocks cutting the volcanics, and there were probably laccolithic sheets and masses invading them; but later mountain-building processes, connected mainly with the elevation of granite batholiths, have greatly obscured the relationships. While terrestrial lava flows and falls of bombs and ashes played the most prominent part in the formation of the Keewatin in many places, submarine lava flows may have taken place also, since the pillow structure is generally regarded as resulting from the action of water on hot lava streams. There is every reason to suppose that then as now there were volcanic eruptions both on land and from the sea bottom.

Through what substratum these volcanic rocks came to the surface is unknown. At present they commonly rest on the gneiss and granite of the Laurentian—deep-seated eruptives of a later age, which have invaded and swept off fragments of the Keewatin rocks in ways showing that they were cold and solid at the time. The floor on which the lavas flowed and the volcanic ashes were rained down has generally vanished, though in places the volcanics rest on sedimentary schists or gneisses of the Couchiching, which will be described later.

In most cases the old volcanoes themselves have disappeared, but the base of one of them, consisting of gabbro, anorthosite, and granite, has been described by Lawson, from Shoal Lake east of Rainy Lake.

It was an age of intense volcanic activity, and the results were just such as we find in the Keweenawan and more recent eruptive

periods; though the rocks are of course far more altered by metamorphism.

The Keewatin of the states near Lake Superior is described as consisting almost entirely of eruptives such as have been referred to above, though bands of iron range rocks occur with them in Minnesota. President Van Hise and others therefore look on the Keewatin as essentially eruptive with the exception of the oldest iron ranges.

It will be shown in succeeding pages that this is by no means true of the Keewatin of Ontario.

KEEWATIN SEDIMENTS

When Lawson began his study of the Lake-of-the-Woods region he was specially impressed with the wide-spread eruptives and ash rocks, though he found associated with them subordinate amounts of sediments such as carbonaceous slates and quartzites; and he defined the Keewatin as essentially an eruptive series. As his work extended eastward, however, he made the acquaintance on Rainy Lake of a great series of sedimentary rocks, to which he gave the name of Couchiching.

The correlation committee which adjusted the terminology of the western Great Lakes region chose the name Keewatin instead of Couchiching for the whole series; so that the Keewatin as now defined includes both eruptives and sediments older than the Laurentian.

By Lawson and later workers in northern Ontario it has been shown that every type of water-formed sedimentary rock is represented in the Keewatin: limestones and dolomites, carbonaceous and ordinary slates, mica schist and gneisses representing more altered muddy sediments, quartzites, arkoses, and graywackes, and even conglomerates and breccias, though the last-mentioned rocks are not always easily separated from agglomerates, etc., of volcanic origin.

With the exception of the Couchiching, most of these sedimentary rocks are not extensively developed in the region studied by Lawson; iron formation occurs only in small outcrops and remained unobserved in the hasty field work of early days.

In reality the iron formation is found in practically every Keewatin area, always near the top of the series, and sometimes with a thickness of 1,000 or 1,500 feet.

The iron formation differs so much from later sediments that some geologists regard it as something peculiar and apart, belonging perhaps to the earth's earliest times and produced only under conditions very different from those of the present. It has been described, for instance, as a chemical sediment deposited in a hot sea where volcanic eruptions were taking place. So many speculations have been indulged in on this fascinating subject that too much space would be required to recapitulate them.

In many places in Ontario, however, the iron formation is so closely associated with commonplace sedimentary materials, slate charged with carbon, arkose, and crystalline limestone, that one can hardly believe it to have been formed under peculiar conditions not repeated in later times.

In any case the other sedimentary rocks, often covering large areas and with considerable thickness, must be looked on as normal products of conditions which have persisted ever since.

In the following pages descriptions will be given of the chief Keewatin sedimentary rocks, and their distribution will be outlined. As the iron formation, because of its economic importance, has been most carefully studied, it will be taken up first.

THE IRON FORMATION IN ONTARIO

In the states near Lake Superior the Keewatin iron formation consists mainly of jasper of varying colors closely interbanded with hematite, less often magnetite. Iron formation of a very similar kind has been found between the Vermilion range in Minnesota and Fort William on Lake Superior, and in smaller areas near Batchawana Bay, Lake Temagami, and in a number of other places in northern Ontario. More commonly in Ontario, however, the silica is in the form of chert, quartzite, or a sandstone-like aggregation of grains, while the interbanded iron ore is mostly magnetite. Probably the differences are largely due to more extensive metamorphism in the latter as compared with the former type.

In most of the regions of Ontario where the iron formation has

been carefully mapped and studied it includes also more or less siderite, or pyrite, or pyrrhotite, so that not the whole of the iron is contained in the oxides.

There is, however, another variety of the formation which has received less attention, consisting of granular silica with little or no iron, but sometimes interbanded with gray or green schistose materials. This appears to be the common form in the far west, near Fort Frances on Rainy River, and near Kenora on the Lake-of-the-Woods. In these localities sandstone-like rocks are found quite extensively with the gray schists described by Lawson as Couchiching. It may be that the sources of iron ran out toward the west, leaving only the silica.

The sandstone-like variety of iron formation, when first found by the present writer, was thought to be an ordinary sediment. It resembles a white or gray or brownish sandstone of even grain, and is often so loosely cemented that the rock may be crumbled in the fingers. Thin sections, however, show little or no clastic structure. The quartz grains are polyhedral individuals which have grown from centers until they met. Every transition may be found between these relatively coarse-textured varieties and the very fine-grained silica, often chalcedonic, of the jaspers. The quartzitic variety occurs in or near the eruptive granite of the Laurentian. In it the anhedra of quartz are firmly cemented together.

As mentioned before, in most places in Ontario the silica and iron ore are accompanied by ordinary sedimentary material. In a number of thin sections sillimanite occurs, a silicate of alumina that must have been recrystallized from clay. On the east shore of Lake Nipigon, and in other places, the banded silica and magnetite are interbedded with gray slate or phyllite and often pass gradually into this rock, which is, of course, a metamorphosed clay. Frequently also a few feet of black carbonaceous slate underlie the iron formation, as at the Helen mine, Michipicoten, and at Grassy Portage on Rainy Lake.

At Goudreau Lake southwest of Missanabie, the iron formation contains a small amount of granular silica with magnetite, and a large amount of pyrite, the sulphide replacing the oxide; and

parallel with it runs a band of crystalline limestone 30 feet thick and more than a mile long.

In the cases just mentioned sediments such as clay, limestone, and carbon were deposited with silica and iron oxide or sulphide. The carbon makes it altogether probable that sea weeds lived on the muddy bottom, so that the waters must have been cool enough for life and free from poisonous substances.

In a number of places near Lake Nipigon the iron ranges include large amounts of arkose as well as the slaty rocks mentioned above. Thin sections present the usual angular or subangular fragments of quartz and feldspar imbedded in a finer grained matrix. The formation of these greenish gray arkoses suggests a land surface of granite or gneissoid rocks exposed to weathering in a cool and moist climate, as shown by Professor Barrell, in his excellent study of *Climates and Terrestrial Deposits*. These rocks cover in all many square miles and must have a thickness of a thousand feet or more, unless greatly reduplicated by folding. Near Poplar Lodge they have a width of a quarter of a mile with dips of from 60° to 80°, though banded jasper and hematite and also a little green schist are interleaved with the arkose, making up perhaps one-tenth of the whole.

THE COUCHICHING PHASE OF THE KEEWATIN

Associated with the iron formation at a number of points on Rainy Lake, Rainy River, near Dryden, etc., one finds gray fine-grained schists and gneisses having the character of the Couchiching as described by Lawson; but these rocks occur in larger areas apart from known iron ranges. They are composed of quartz, biotite, sometimes muscovite, and often some orthoclase or plagioclase; and they frequently contain sillimanite, garnet, and staurolite, or pseudomorphs after staurolite. They are evidently sandy or clayey sediments recrystallized, and may be compared with the sedimentary gneisses and quartzites of the Grenville series of eastern Canada so well described by Adams.

The materials of which they were formed must have been derived from granite or gneiss and not from the basic eruptives with which they are associated. In the decay of the original rocks much of the feldspar must have been decomposed, the alkalies

being removed. They are often seen resting on Laurentian gneiss, but the latter was not the source of the sand of which they were formed, since the Laurentian is everywhere in eruptive relationships with the Couchiching and hence is of later age. The gneiss penetrates the overlying schist and has often broken off slices which have been floated away by the molten flood.

As mapped by Lawson, Couchiching schists are widely distributed on Rainy Lake, which must be looked on as the type locality. In my field work many outcrops of these rocks have been studied near Rice Bay, Grassy Portage, Gash Point, Goose Island, Sand Point Island, and at other places on the way eastward toward Bear's Passage; and I can confirm Lawson's description of them.

Near Grassy Portage and Nickel Lake they include iron range rocks of a somewhat unusual variety, in which pyrite and pyrrhotite largely replace iron oxides; and some miles to the west on Rainy River, below Fort Frances, they are found with sandstone-like silica almost free from iron.

In general, however, the Couchiching schists occur in large areas by themselves, always dipping at high angles (60° to 80°), often having widths across the strike of hundreds of yards, sometimes of a mile or more. They may have various relations to the green Keewatin schists, sometimes underlying them and at others appearing to be interbedded with them. Near Shoal Lake there are, however, schists resembling the Couchiching which lie above the basal Huronian conglomerate and are evidently of much later age.

Lawson maps the Couchiching as extending from west to east across almost the whole Rainy Lake sheet, a distance of more than 60 miles; and the Hunter's Island and Seine River sheets, to the southeast and east respectively, contain large areas also, as mapped by Lawson, W. H. Smith, and McInnes. The whole length shown is about 90 miles, and the breadth 24 miles.

Lawson estimates the thickness of the Couchiching at about 25,000 feet, but in such ancient rocks, now folded in mountain structures, it is possible and perhaps probable that this thickness is excessive. The real thickness may be repeated many times by folding, but it can hardly be less than some thousands of feet.

COUCHICHING IN OTHER REGIONS

Schists of the Couchiching type are widely found in northern Ontario. They occur at various points on Lake-of-the-Woods, e.g., on the southern edge of the Grande Presqu'isle, and near the Scramble mine east of Kenora, where they are accompanied by a band of granular silica having the look of sandstone. They are found also in large areas near Clearwater and Manitou Lakes, north of Rainy Lake, and extend for miles along the railway east of Dryden, here associated with the iron formation.

Mica schist or gneiss of the same kind, and also arkose and slate, are found on Sandy and Minnitakie Lakes north of Wabigoon; so that areas of Couchiching occur for a distance of more than 100 miles north of the Minnesota boundary.

Within the past year or two similar rocks have been described by E. S. Moore from near Round Lake, north of Lake Nipigon, and by the present writer from Black Sturgeon Lake to the south of Lake Nipigon.[1] In 1908 A. L. Parsons gave an account of schists like the Grenville gneisses on the Algoma boundary[2] and in the following year gray schists of the same sort were observed by myself north of Jackfish and along the shore of Long Lake. The Couchiching here has a width of several miles across the strike, with dips of 60° or 70°. W. J. Wilson in a "Summary Report on the Algoma and Thunder Bay Districts"[3] describes such gneisses containing garnet, cordierite, sillimanite, etc., as occurring extensively, and compares them with the Couchiching and also with the Grenville gneisses; and W. H. Collins gives an account in the same report of rocks of the same kind southwest of Long Lake, containing garnets and graphite. He mentions quartzite and arkose as occurring there also.[4]

There are sillimanite gneisses and arkose, as well as ordinary and carbonaceous slate, in various places in the Michipicoten region 150 miles southeast of Long Lake, but the known area of these rocks is not very large.

Mica schist with staurolite has been found by M. B. Baker in the Abitibi region more than 200 miles to the east, and he men-

[1] *Bur. Mines* (1909), 144 and 158.

[2] *Ibid.* (1907), 101.

[3] *G.S.C.*, No. 980, 5 and 6.

[4] *Ibid.*, No. 1081, 14.

tions also graphitic slate, rusty weathering dolomite, and a coarse fragmental series accompanying typical iron range rocks. He suggests that the fragmental rocks may imply a break in the Keewatin, and quotes Miller and Brock as favoring this view.[1]

Morley E. Wilson briefly describes similar rocks from the Temiscaming region to the south as follows: "On the north shore of Larder Lake there is a belt—nearly a mile wide—of interbanded phyllites, slates, and graywackes, which parallels the lake shore for several miles. These rocks have a nearly vertical attitude; a uniform northeasterly strike; are in places graphitic; and locally contain small quantities of iron ore formation."[2]

From the citations given above it will be seen that sedimentary rocks like the Couchiching or the Grenville series are widely spread in the Keewatin of Ontario. They often cover large areas and in many places equal or surpass the eruptives in extent. It is true that there are large gaps where no ordinary Keewatin sediments are known to exist, but doubtless many small areas remain undiscovered because unlooked for. A few years ago no one could have foretold that the iron formation would be found in almost every Keewatin area in Ontario, but we now know that this is the case.

The Keewatin sediments can no longer be overlooked as negligible in any account of the Canadian Archaean. In reality these sedimentary rocks are the true Keewatin, and the accompanying eruptives and ash rocks must be considered less important, in a sense accidental, members of the series.

The Keewatin of the states near Lake Superior seems from the published accounts to contain a much smaller proportion of sedimentary materials than of volcanics; which no doubt accounts for the prevalent opinion among American geologists that the Keewatin, or the older part of the basal complex, consists essentially of eruptive rocks.

RELATIONS OF THE KEEWATIN TO THE GRENVILLE SERIES

Having shown that the Keewatin contains sedimentary rocks of every kind, some of them having a wide extent and a great thickness, it is natural to compare them with the ancient sedi-

[1] *Bur. Mines* (1909), 275–78.

[2] *Sum. Rep., Geol. Sur.* (1909), 175.

mentary rocks of the Grenville and Hastings series of southern and eastern Ontario and Quebec. These were studied long ago and were originally included in the Laurentian; though now the term Laurentian is confined to the eruptive granites and gneisses which penetrate them and rise from beneath them.

The nearest Grenville rocks to the Keewatin sediments described above begin about 150 miles south of the Larder Lake region in the township of Loring, just south of Lake Nipissing, where graphitic schist occurs. Between this and Parry Sound crystalline limestone and gray garnetiferous schists and gneisses are widely found and were compared by myself in 1900 with the western Couchiching.[1] There are also green schists in the region suggesting western Keewatin schist of eruptive origin.

In eastern Ontario the Grenville and Hastings series often greatly resemble the Keewatin, including banded silica and iron ore, slate, quartzite, and fine-grained gray sedimentary gneiss containing graphite. There are, however, some marked differences. Limestones are rare in the western Keewatin but make the most prominent rock in the Grenville and Hastings series, even reaching a thickness of more than 50,000 feet, according to Adams; while volcanic rocks play a larger part in the west than in the east. Just how the eastern Archaean is related to the western is still a matter of discussion, Adams thinking that the Grenville and Hastings series are both probably the equivalent of the western Huronian, while Miller believes that the Hastings series represents the Huronian, and the Grenville series the Keewatin.

From my own observations it may be said that a considerable part of the Grenville rocks are closely like the western Keewatin. If they were found in the Upper Lakes region they would certainly be classed on lithological grounds as Keewatin; and the two series of rocks are also related in the same way to the Laurentian batholiths. In the east as well as in the west these great eruptive masses are later than the overlying rocks and have pushed up through them, often nipping them in as synclines. In neither case has the foundation on which these earliest sediments were laid down been preserved.

[1] *Bur. Mines* (1900), 169; also 182.

CONCLUSIONS

It has been shown in the foregoing pages that the oldest known rocks in Canada, the Keewatin in the west, and the Grenville and Hastings series in the east, stretching for 900 or 1,000 miles across the country, include large amounts of sedimentary materials. Among these rocks are limestones and dolomites, slate of ordinary kinds and also slate charged with carbon, mica schist, and gneiss having the composition of clayey sandstones, arkoses with angular bits of quartz and feldspar, and in a few places also coarser fragmental rocks. In the east the seas were clearer and deeper, so that limestone predominated. In the west volcanic activity was very pronounced and lava streams, lapilli, and ashes occur on a large scale, either mixed with the water-formed sediments or making up thousands of feet of rock in themselves.

There must have been great land surfaces from which rivers flowed, bringing down sand and clay. Much of the material suggests well-weathered products derived from granite and gneiss; but the arkoses, which are widespread and thick, probably imply a cool and moist land surface. The sea contained plants to furnish the carbon, often reaching several per cent in slates, gneisses, and limestone; and the limestones hint at calcareous algae or animals having hard parts.

All varieties of geological work seem to have been under way in pre-Huronian times as they have been ever since; and there is no evidence of special primeval conditions different from those known to later geology.

In this paper the earliest Canadian sediments have been discussed from the point of view of climate and physical conditions, and no attempts have been made to marshal the evidence from other lands; but the Canadian Keewatin and Grenville are probably as old as any known rocks, and the same conclusions have been reached from a study of the Archaean rocks of Europe and other continents. Similar sediments penetrated by granites and gneisses occur in the Lewisian of Scotland and the Ladogian of Finland and other parts of Scandinavia. Last summer in Sweden I had the opportunity to study Archaean sediments exactly like our Keewatin, so that the conclusion reached in this paper may be

extended to cover the most ancient formations of the Old World also.

Though the Keewatin and Grenville series are the oldest known formations in America, it is evident that they do not take us back to the commencement of geological time, since they include clastic sediments that imply the weathering and erosion of previous rocks before they were spread out on the sea bottom. We have extended our outlook much farther into the past, but there is still an impenetrable background beyond. We shall perhaps never be able to say "in the beginning"; but we may safely say that there is no hint of a molten earth in process of cooling down. If the earth was ever hot it had so far cooled down before the oldest known rocks were formed as to allow air and water and life to do their work in the world very much as they do now. If the earth ever passed through a period of great heat it was at a time too remote in the past to leave a geological record or to have any special interest for the geologist.

THE AGENCY OF MANGANESE IN THE SUPERFICIAL ALTERATION AND SECONDARY ENRICHMENT OF GOLD DEPOSITS[1]

WILLIAM H. EMMONS

I. INTRODUCTION AND SUMMARY

Ferric iron, cupric copper, and manganitic manganese are present in many mineral waters, and under certain conditions any one of them will liberate chlorine from sodium chloride in acid solutions. Nascent chlorine dissolves gold. Each of these compounds releases chlorine at high temperatures, or in concentrated solutions. In cold, dilute acid chloride solutions, ferric iron will not give nascent chlorine in appreciable quantity in 34 days, and cupric copper is probably even less efficient; but manganitic compounds liberate chlorine very readily. In a cold solution containing only 1,418 parts of chlorine per million, considerable gold is dissolved in 14 days when manganese is present. It should be expected, then, that those auriferous deposits, the gangues of which contain manganese, would show the effects of the solution and migration of gold more clearly than non-manganiferous ores.

Gold thus dissolved is quickly precipitated by ferrous sulphate. It is, therefore, natural to suppose that gold in such solutions could not migrate far through rocks containing pyrite, since it would be precipitated by the ferrous sulphate produced through the action of oxidizing waters, or the gold solution itself, upon the pyrite. But the dioxide and higher oxides of manganese react immediately upon ferrous sulphate, converting it to ferric sulphate, which is not a precipitant of gold. Consequently, manganese is not only favorable to the solution of gold in cold, dilute mineral

[1] Published, in a more amplified form, by permission of the Director of the U.S. Geological Survey in *Bull. 46, American Institute of Mining Engineers*, 768–837, October, 1910.

waters, but it also inhibits the precipitating action of ferrous salts, and thus permits the gold to travel farther before final deposition.

These statements apply to the action of surface waters descending through the upper parts of an auriferous ore deposit, since such waters are cold, dilute, acid (i.e., oxidizing) solutions. In deeper zones, where they attack other minerals, they lose acidity, until the manganese compounds, stable under oxidizing conditions, are precipitated together with the gold. Thus, manganite, as well as limonite and kaolin, is frequently found in secondary (i.e., dissolved and reprecipitated) gold ores. Moreover, in the precipitation of secondary copper and silver sulphides, ferrous sulphate is generally formed; and, consequently, the secondary silver or copper sulphides frequently contain gold.

Those deposits in the United States in which a secondary enrichment in gold is believed to have taken place are, almost without exception, manganiferous. Since secondary enrichment is produced by the downward migration, instead of the superficial removal and accumulation, of the gold, it should follow that both gold placers and outcrops rich in gold would be found more extensively in connection with non-manganiferous deposits; and this inference is believed to be confirmed by field-observations.

Among the papers which treat the superficial alteration and secondary enrichment of copper, gold, and silver deposits are those of S. F. Emmons,[1] Weed,[2] Penrose,[3] Winchell,[4] Van Hise,[5] Kemp,[6] and Rickard.[7] The processes upon which the changes depend are clearly outlined in these, and subsequent work has, in a large measure, confirmed the premises stated. The chemical

[1] "The Secondary Enrichment of Ore-Deposits," *Trans.*, XXX, 177–217 (1900).

[2] "The Enrichment of Gold and Silver Veins," *Trans.*, XXX, 424–48 (1900).

[3] "The Superficial Alteration of Ore-Deposits," *Journal of Geology*, II, No. 3, 288–317 (Apr.-May, 1904).

[4] *Bulletin of the Geological Society of America*, XIV, 269–76 (1902).

[5] "Some Principles Controlling the Deposition of Ores," *Trans.*, XXX, 27–177 (1900).

[6] "Secondary Enrichment in Ore-Deposits of Copper," *Economic Geology*, I, No. 1, 11–25 (Oct.-Nov., 1905).

[7] "The Formation of Bonanzas in the Upper Portions of Gold-Veins," *Trans.*, XXXI, 198–220 (1901).

laws and physical conditions controlling secondary enrichment have been reviewed in several reports more recently published. The papers of Lindgren, Ransome, Spencer, Boutwell, Irving, Graton, McCaskey, Spurr, and Garrey and Ball are particularly valuable. Such work has shown that the secondary enrichment of pyritic copper deposits is a very inportant process; that many silver deposits are enriched by superficial agencies; but that many gold deposits do not show deep-seated secondary enrichment.

T. A. Rickard[1] has brought out clearly the processes by which gold deposits may be enriched relatively near the surface in the oxidized zone by the removal of valueless minerals which are more readily dissolved than gold. On the problem of deeper-seated precipitation of gold below the zone of oxidation there is less evidence. In some mines, however, the transportation and deep-seated precipitation of gold is clearly shown, as was pointed out long ago by Weed.

While engaged in the investigation of certain auriferous deposits in the Philipsburg quadrangle, Montana, for the U.S. Geological Survey, I was confronted by evidence gained in two important mines, which seemed to be conflicting on this point. In one of them, the Cable mine, there was no evidence that gold had been concentrated by cold solutions below the zone of oxidation, but in the Granite-Bimetallic Lode there was enrichment of both gold and silver below the zone of leached oxides.

Although the ores of the two deposits differ in other respects, the most striking difference is in the manganese content. The use of manganese in the chlorination process to give free chlorine, which dissolves gold, is well known. Le Conte[2] said as early as 1879 that free chlorine is the most important natural solvent of gold, and Pearce, in 1885, recorded experiments in which gold had been dissolved in hot sulphate solutions with common salt and manganese dioxide.[3] Don obtained similar results with more dilute solutions.[4] It appeared desirable, therefore, to ascertain whether these reactions are carried on in cold dilute solutions

[1] *Op. cit.* [2] *Elements of Geology*, p. 285.

[3] *Proceedings of the Colorado Scientific Society*, II, 3 (1885–87).

[4] *Trans.*, XXVII, 654 (1897).

similar to mine waters; and Nicholas Sankowsky and Clarence Russell, in a seminar on the Chemistry of Ore Deposits, which I conducted at the University of Chicago, compiled all available analyses of waters from gold and silver mines in non-calcareous rocks. A. D. Brokaw conducted a series of experiments, using cold dilute solutions of compositions suggested by the analyses. He performed other experiments applicable to the study of the precipitation of gold, showing the action of manganese dioxide on ferrous salts. During the progress of this investigation, W. J. McCaughey published his valuable paper on the solvent effect of ferric and cupric salt solutions upon gold,[1] and this in a large measure supplemented the work carried on in the seminars at the University of Chicago.

The experiments conducted by Brokaw showed that manganese in the presence of chlorides and sulphates is very much more efficient in the reactions dissolving gold than are the other salts common in mine waters. To verify these results by field-evidence, the review of the literature was taken up in greater detail, and there also the results indicate a marked difference in the behavior of the cold dilute mineral waters in the presence and in the absence of manganese.

Lindgren's classification of the gold deposits of North America has been of great value in reviewing these deposits; since in the United States manganese is rarely a gangue mineral in the primary gold deposits as old as the early Cretaceous California gold veins, whereas it is frequently present in appreciable quantities in those deposits which were formed nearer the surface and which are related to intrusives of Tertiary age.[2] I have not attempted to review exhaustively the evidence afforded by deposits outside of the United States with respect to the hypothesis suggested, but some of these deposits appear to supply accurate confirmatory data.

In a statistical study of outcrops, to ascertain whether gold is more extensively leached in manganiferous lodes than in the

[1] *Journal of the American Chemical Society*, XXXI, No. 12, 1261–70.

[2] W. Lindgren, "The Relation of Ore-Deposition to Physical Conditions," *Economic Geology*, II, No. 2, 105–27 (Mar.-Apr., 1907).

outcrops of those which do not carry manganese, and whether placers are more frequently developed in connection with non-manganiferous lodes, the reports of Dr. R. W. Raymond[1] have been of great value.

I wish to acknowledge my indebtedness to my colleagues of the U.S. Geological Survey, and to many other geologists whose accurate observations I have drawn upon to test the hypothesis. Their conclusions respecting the secondary enrichment of gold appear to support the hypothesis, and, differing as they do with respect to the migration of gold in particular deposits, they become reconciled when inspected from this viewpoint, and thus they are themselves supported. Dr. R. C. Wells has read critically certain portions of this paper, where the principles of physical chemistry are involved.

II. SALTS CONTAINED IN THE WATERS OF GOLD AND SILVER MINES IN NON-CALCAREOUS ROCKS

Sankowsky and Russell, utilizing all data available to them, recalculated the analyses to the ionic form of statement, and made the general average given in Table I.

Sulphates.—Primary gold ores generally carry pyrite, which, oxidizing at or near the surface, yields ferrous sulphate, ferric sulphate, and sulphuric acid. The acid is not formed directly from galena, PbS, or from zinc-blende, ZnS; but pyrite, FeS_2, carries more sulphur than is required to supply SO_4 to satisfy the iron, even if ferric sulphate, $Fe_2(SO_4)_3$, is formed instead of $FeSO_4$. As shown by Buehler and Gottschalk, galena and zinc-blende dissolve much more slowly in the absence of FeS_2. The reaction probably requires free acid, which the iron sulphide, owing to its excess of sulphur, supplies. The sulphuric acid from pyrite is increased also by the hydrolization of ferric sulphate, and the deposition of limonite.

In Table I the sulphate radical is nearly ten times as great as all other negative ions and is also in excess of bases, so that on any basis of adjustment to form salts much H_2SO_4 remains. The table shows also an average of 97.26 parts per million of hydrogen, indicating the strongly acid character of the solutions.

[1] *Mines and Mining West of the Rocky Mountains* (1868–75).

Chlorides.—Chlorine is present in most mine waters. In 22 out of the 29 analyses it is reported as traces or as determined quantities. The average of 29 analyses shows 873 parts per million, but if the one abnormally rich sodium-chloride water of Silver Islet, Lake Superior, is excluded, the remaining 28 analyses show but 111 parts per million. This figure is probably a better average. There are several sources of the chlorine in mine waters.

TABLE I

Average of 29 Analyses of Waters Taken from Gold, Silver, and Gold-Silver Mines in Non-Calcareous Rocks

(*Compiled by N. Sankowsky and C. Russell*)

	Parts per Million	Number of Determinations
Cl^a	873.10	22
SO_4	7,292.29	13
CO_3	77.59	7
$NO_3{}^a$	0.06	1
PO_4	0.00	traces in 2
SiO_2	34.94	12
K	17.25	7
Na^a	261.20	9
Li	0.10	1
Ca	295.00	11
Sr	0.06	1
Mg	242.44	9
Al	333.65	6
Mn	30.91	6
Ni	trace	traces in 3
Co	trace	traces in 3
Cu	5.09	2
Zn	2.70	5
Fe^{ii}	277.66	22
Fe^{iii}	603.07	25
H (in acids)	97.26	10

The salt in sedimentary rocks may be dissolved by ground-water. From the available analyses it appears that this source is of less importance than would be supposed. The chlorine content of composite samples of 78 shales and of 253 sandstones was only a trace, while an analysis of a composite of 345 limestones showed only 0.02 per cent.[1] In some rocks chlorine is present probably as NaCl in the solid particles contained in fluid inclusions. The work of R. T. Chamberlin, A. Gautier, and others has shown that many granular igneous rocks, when heated to high temperatures,

[1] F. W. Clarke, *Bulletin No. 330, U.S. Geological Survey*, 27(1908).

give off gases equal to several times their own volume. While further inquiry of this character is desirable, it is probably true that in general but little chlorine is present in such gases. But gases from certain volcanic rocks, such as obsidian, often contain a high proportion of chlorine and chlorides. Albert Brun[1] has shown that some of the Krakatoa lavas yield gases which equal about one-half the volume of the rock, and that more than half of such gases consist of chlorine, hydrochloric acid, and sulphur monochloride. The average chlorine content of igneous rocks is, according to F. W. Clarke, 0.07 per cent.

Chlorine is present in nearly all natural waters. Its chief source is from finely divided salt or salt water from the sea and from other bodies of salt water. The salt is carried by the wind and precipitated with rain.[2] The amount of chlorine in natural ponded waters varies with remarkable constancy with the distance from the shore. The isochlores parallel the shore line with great regularity, as shown by the map in Jackson's report. The chlorine contributed from this source even near the seashore appears small; but it may be further concentrated in the solutions by evaporation or by reactions with silver, lead, etc., forming chlorides, which in the superficial zone may subsequently be changed to other compounds. Penrose,[3] discussing the distribution of the chloride ores, pointed out long ago that they form most abundantly in undrained areas.

Carbonates and alkaline earths.—The analyses in Table I do not include those from mines in limestones. The carbonate reported gives an average of 77 parts per million. Even in igneous rocks considerable calcium (295 parts per million) and magnesium (242 parts) are carried by the waters. They are derived in part from reactions between the acid sulphates and the silicates of the wall-rock.

[1] "Quelques recherches sur le volcanisme aux volcans de Java. Cinquième partie. Le Krakatau," *Archives des sciences physiques et naturelles*, Genève, XXVIII, No. 7 (juillet, 1909).

[2] D. D. Jackson, "The Normal Distribution of Chlorine in the Natural Waters of New York and New England," *Water Supply and Irrigation Paper No. 144, U.S. Geological Survey* (1905).

[3] *Journal of Geology*, II, No. 3, 314 (April-May, 1894).

Alumina.—In some waters aluminum sulphate is abundant (the average of aluminum, 333 parts per million). It forms where sulphate waters attack kaolin, setting free SiO_2 and taking alumina into solution.

Nitrates.—Nitrates are not abundant in mine waters. In one analysis only[1] is NO_3 reported (1.60 parts per million), and this in a deep-seated water of questionable genesis.

Phosphates.—Traces only of PO_4 are reported from two mine waters; others contained none, if determinations were made.

Silica.—Silica (35 parts per million) appears high for acid waters. The analyses include a manganiferous sulphate water from the Comstock, abnormally high in silica.[2]

Iron.—Iron is the most abundant metal in the waters of gold mines. Ferric iron (603 parts per million) is, according to these analyses, more than twice as abundant as ferrous iron (277 parts per million). Ferrous iron is much more abundant below than above the water-table.

Manganese.—If manganiferous minerals are present in the primary ore, they oxidize in the upper portion of the deposit to manganese dioxide or other high oxides of manganese; and these, in turn, oxidize ferrous sulphate, in the presence of sulphuric acid, to ferric sulphate.

Copper.—One analysis shows 147 parts of copper per million. Two other analyses show traces. Small amounts must be present in many other waters, since gold ores often carry copper. Possibly, small traces of the heavy metals were not looked for in many of the waters analyzed.

III. CHEMICAL EXPERIMENTS IN THE SOLUTION AND DEPOSITION OF GOLD

The migration of gold in the deposits takes place at low temperatures. At the surface the temperatures range between 0° and 50° C. and pressures do not exceed one atmosphere. With the normal gradient of increase, the temperatures, even several

[1] Geyser Mine, Silver Cliff, Colo. See S. F. Emmons, *Seventeenth Annual Report, U.S. Geological Survey*, Part II, 462 (1895–96).

[2] *Bulletin of the Department of Geology, University of California*, IV, No. 10, 192 (1904–6).

thousand feet below water level, would not exceed 100° C., and in the main are considerably lower. The general character and, approximately, the concentration of the solutions are known and the conditions are fairly constant. From the mass of chemical data relating to the subject, the following experiments are particularly suggestive in connection with the present problem.

1. Stokes[1] placed gold leaf in a solution containing 25 gm. per liter of ferric sulphate, and, after heating to 200° C., found that not a trace of gold had been deposited in the cold part of the sealed tube in which the experiment was carried on. This experiment does not confirm the statement frequently made that ferric sulphate will dissolve gold.

2. Don[2] exposed to air, gold and auriferous sulphide ores in solutions containing from 1 to 20 gm. of ferric chloride and ferric sulphate per liter of water; after several months no gold had been dissolved.

3. W. J. McCaughey,[3] upon boiling for several hours 50 c.c. of HCl (sp. gr. 1.178) diluted to 125 c.c. with 250 mg. of gold, found there was no loss of gold.

4. In a bent tube Stokes[4] heated gold leaf for 16 hours at 200° C. in a solution composed of 85 gm. of cupric chloride and 133 c.c. of 20 per cent HCl in a liter of water. The gold leaf was dissolved and redeposited in the upper portion of the tube. He writes the reaction as follows:

$$Au + 3CuCl_2 \leftrightharpoons AuCl_3 + 3CuCl.$$

5. Stokes[5] heated gold leaf to 200° C. in a closed tube containing a solution of 25 gm. of ferric sulphate and 0.01 gm. of NaCl. Gold was dissolved in 40 hours.

6. Stokes[6] found that at 200° C. gold leaf was dissolved in a mixture of 2 parts of 20 per cent solution of ferric chloride and 1 part of 20 per cent solution of HCl.

[1] *Economic Geology*, I, No. 7, 650 (July-Aug., 1906).

[2] *Trans.*, XXVII, 598 (1897).

[3] *Journal of the American Chemical Society*, XXXI, No. 12, 1263 (Dec., 1909).

[4] *Op. cit.*, I, 649.

[5] *Economic Geology*, I, No. 7, 650 (July-Aug., 1906).

[6] *Ibid.*, 650.

7. W. J. McCaughey[1] dissolved gold at from 38° to 43° C., in hydrochloric acid solutions of ferric sulphate. The results are indicated by the curves in Fig. 1. Solution *A* contained 1 gm. of iron, introduced as ferric sulphate, and 25 c.c. of HCl (sp. gr. 1.178) in a solution diluted to 125 c.c. containing 250 mg. of gold rolled to 0.009 inch. Solution *B* contained the same amount of iron sulphate and 50 c.c. of HCl. Solution *C* contained 2 gm. of Fe as ferric sulphate and 25 c.c. of HCl. Solution *D* had twice

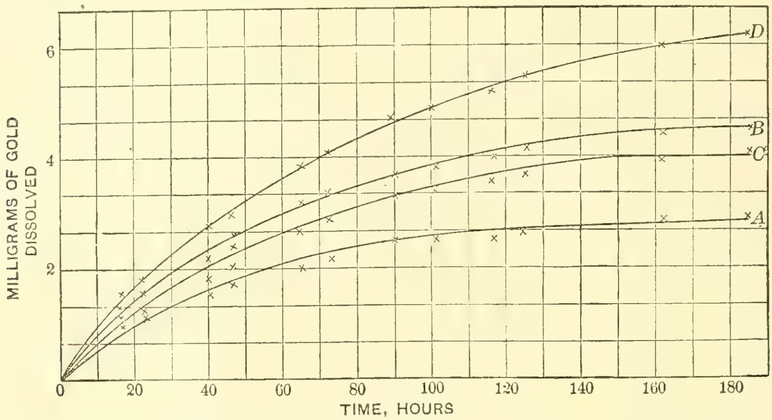

Fig. 1.—Diagram Showing the Rate of Solution of Gold in Concentrated Solutions of Hydrochloric Acid and Ferric Sulphate. (Illustrating Experiment 7, by McCaughey.)

the concentration of *A*. The diagram shows the amount of gold dissolved after different periods of treatment.

8. McCaughey[2] found that gold is dissolved at from 38° to 43° C. in a strong solution of cupric chloride and HCl. The amounts dissolved are shown by the curves in Fig. 2. Solution *A* contained 1 gm. of Cu as cupric chloride and 25 c.c. of HCl (sp. gr. 1.178); solution *B*, 1 gm. of Cu as $CuCl_2$, and 50 c.c. of HCl; solution *C*, 2 gm. of Cu as $CuCl_2$ and 25 c.c. of HCl; and solution *D*, 2 gm. of Cu as $CuCl_2$ and 50 c.c. of HCl; the final solution being in all cases diluted to the volume of 125 c.c. The

[1] *Journal of the American Chemical Society*, XXXI, No. 12, 1263 (Dec., 1909).

[2] *Ibid.*, 1264.

diagram shows that *D*, which was twice as concentrated as *A*, dissolved about 12 times as much gold.

9. Richard Pearce[1] placed native gold in a flask containing hydrated manganese dioxide with 40 gm. of salt and 5 or 6 drops of H_2SO_4. After heating for 12 hours appreciable gold had been dissolved.

10. T. A. Rickard[2] extracted 99.9 per cent of the gold from manganiferous ore with a solution of ferric sulphate, common salt, and a little H_2SO_4.

11. Don[3] found that 1 part of HCl in 1,250 parts of H_2O, in the presence of MnO_2, dissolves appreciable gold.

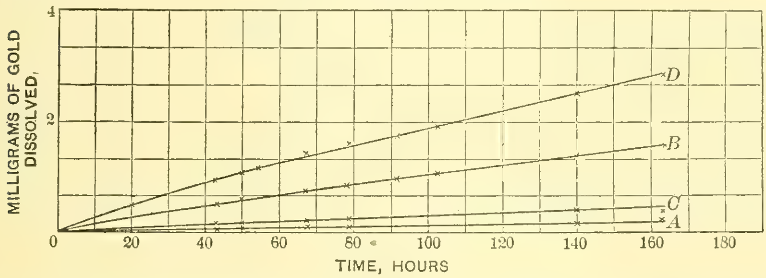

FIG. 2.—Diagram Showing the Solubility of Gold in Concentrated Solutions of Hydrochloric Acid and Cupric Chloride. (Illustrating Experiment 8, by McCaughey.)

A number of experiments on the solubility of gold in cold dilute solutions were made by A. D. Brokaw.[4] The nature of these experiments is shown by the following statements, in which (*a*) and (*b*) represent duplicate tests:

12. $Fe_2(SO_4)_3+H_2SO_4+Au$.
 (*a*) no weighable loss. (34 days.)
 (*b*) no weighable loss.

13. $Fe_2(SO_4)_3+H_2SO_4+MnO_2+Au$.
 (*a*) no weighable loss. (34 days.)
 (*b*) 0.00017 gm. loss.[5]

[1] *Trans.*, XXII, 739 (1893).

[2] *Trans.*, XXVI, 978 (1896).

[3] *Trans.*, XXVII, 599 (1897).

[4] *Journal of Geology*, XVIII, No. 4, 321–26 (May-June, 1910).

[5] This duplicate was found to contain a trace of Cl, which probably accounts for the loss.

14. $FeCl_3+HCl+Au$.

(*a*) no weighable loss. (34 days.)

(*b*) no weighable loss.

15. $FeCl_3+HCl+MnO_2+Au$.

(*a*) 0.01640 gm. loss. Area of plate, 383 sq. mm. (34 days.)

(*b*) 0.01502 gm. loss. Area of plate, 348 sq. mm.

In each experiment the volume of the solution was 50 c.c. The solution was one-tenth normal with respect to ferric salt and to acid. In experiments 13 and 15, 1 gm. of powdered manganese dioxide was also added. The gold, assaying 999 fine, was rolled to a thickness of about 0.002 inch, cut into pieces of about 350 sq. mm. area; and one piece, weighing about 0.15 gm., was used in each duplicate.

To approximate natural waters more closely, a solution was made one-tenth normal as to ferric sulphate and sulphuric acid, and one twenty-fifth normal as to sodium chloride. Then 1 gm. of powdered manganese dioxide was added to 50 c.c. of the solution, and the experiment was repeated. The time was 14 days.

16*a*. $Fe_2(SO_4)_3+H_2SO_4+NaCl+Au$.

No weighable loss.

16*b*. $Fe_2(SO_4)_3+H_2SO_4+NaCl+MnO_2+Au$.

Loss of gold, 0.00505 gm.

The loss is comparable to that found in experiment 15, allowing for the shorter time and the greater dilution of the chloride.

To determine whether the free acid or the ferric chloride is the solvent, experiment 17 was made, in which 50 c.c. of one-tenth normal HCl was used with 1 gm. of powdered MnO_2.

17. $HCl+MnO_2+Au$.

Loss of Au, 0.01369 gm. Time, 14 days.

In experiment 18, sodium hydroxide was added to 50 c.c. of one-tenth normal ferric chloride solution until the precipitate formed barely redissolved on shaking, after which 1 gm. of powdered MnO_2 was added.

18. $FeCl_3+MnO_2+Au$.

Loss of Au, 0.00062 gm. Time, 14 days.

These results show that, in the presence of manganese dioxide, free hydrochloric acid is more efficient than ferric chloride. The same amount of chlorine was present in both solutions.[1]

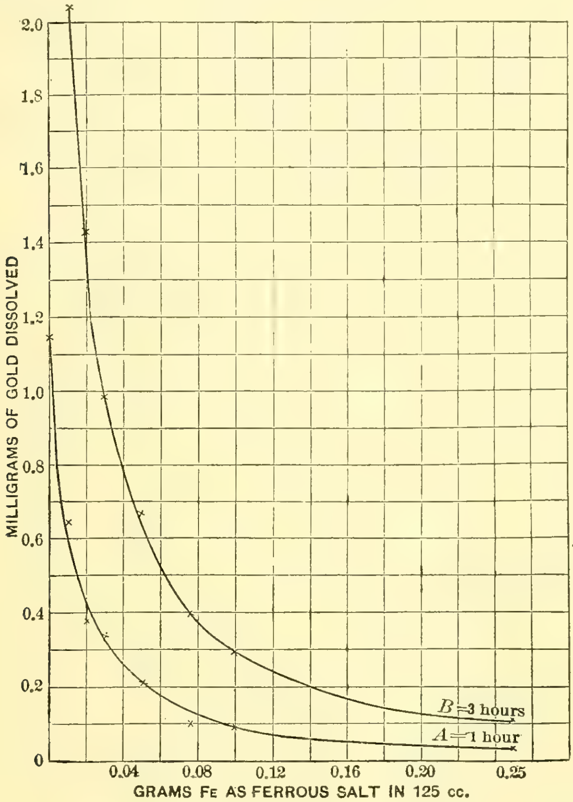

FIG. 3.—Diagram Illustrating the Effect of Ferrous Sulphate in Suppressing the Solubility of Gold in Ferric Sulphate Solutions, where Gold is Dissolved as Chloride. (Illustrating Experiment 19.)

19. McCaughey's experiments show the effect of very small amounts of ferrous sulphate on solutions of gold in ferric sulphate. To a solution, 125 c.c., containing 1 gm. of iron as ferric sulphate and 25 c.c. of HCl, ferrous sulphate was added in quantities containing from 0.01 to 0.25 gm. of ferrous iron. The solutions were immersed in boiling water and subsequently 250 mg. of gold was

[1] Brokaw, *Journal of Geology*, XVIII, No. 4, 322–23 (May-June, 1910).

added. The dissolved gold was determined at the end of 1 hour and 3 hours. At the end of 3 hours the gold dissolved was greater, probably because some ferrous sulphate had changed to ferric sulphate. Even 0.01 gm. of the ferrous iron greatly decreases the solubility of gold in the ferric sulphate and HCl solution, and 0.25 gm. of ferrous sulphate drives nearly all the gold out of solution. These experiments are illustrated by Fig. 3. The lower curve represents conditions at the end of 1 hour, the upper curve at the end of 3 hours, when some of the ferrous salt had oxidized by contact with the air.

20. To determine the rate at which ferrous sulphate, in the presence of sulphuric acid and manganese dioxide, would be oxidized to the ferric salt, Brokaw made the following experiment:

One hundred c.c. of 1.6 normal FeSO was acidified with sulphuric acid and shaken vigorously with 5 gm. of powdered MnO_2. After 5 minutes the solution was filtered. No ferrous iron was detected by the ferricyanide test, showing that the iron had been completely oxidized to the ferric state.

IV. DISCUSSION OF EXPERIMENTS

Nitrates.—Dilute acid nitrate-chloride waters readily dissolve gold, since they are equivalent to weak aqua regia. The chlorine set free by the reaction oxidizing HCl is more active than a solution of chlorine in water, and converts gold into gold chloride.

In the reaction by which gold is dissolved in chloride solution its solvent power may be ascribed to its "nascent" state. In such reactions the presence of an element with more than one valence is a necessary condition and its valence is reduced as gold passes into solution.

The reaction of $3HCl+HNO_3$, giving nascent chlorine, may be written as follows:[1]

$$Cl-\boxed{H+H-O-}\overset{\overset{O}{\|}}{N}\boxed{=O+2H}Cl\rightarrow 2H_2O+Cl_2+Cl-N=O.$$

When nascent chlorine reacts with gold, it forms soluble gold chloride.

[1] Alexander Smith, *General Inorganic Chemistry*, 449 (1907).

In the 29 analyses of mine waters NO_3 is reported from but one. Possibly nitrates are more abundant than is indicated by the analyses; and if so, they must increase the solvent power of chloride solutions; but the data at present available do not indicate that they affect the superficial reactions to any important extent.

Manganese oxides.—That gold is dissolved in moderately dilute solutions containing salt and manganese oxides is shown by experiments 11, 15, and 16. The reaction with manganese used to prepare chlorine commercially is illustrated by the following equation. (The reaction is not so simple as stated. It is discussed later.)

$$Mn^{iiii}O_2+2NaCl+3H_2SO_4 \rightarrow 2H_2O+2NaHSO_4+Mn^{ii}SO_4+2Cl.$$

At the beginning of the reaction the manganese has a valence of four; at the end a valence of two. With acid the reaction may be as follows:

$$MnO_2+4HCl \rightarrow 2H_2O+MnCl_2+Cl_2.$$

Besides the presence of a chloride, some other conditions are essential to the solution of gold. There appear to be two. One is that some other substance must also be present which is capable of being reduced so as to liberate chlorine—as, for example, a ferric salt which may be reduced to the ferrous, a cupric to the cuprous, the higher manganese salts to the lower, etc. The other is the evolution of "nascent" chlorine. This is particularly illustrated by the action of aqua regia or the production of chlorine by hydrochloric acid and pyrolusite. In short, any of a number of methods of producing free chlorine would be effective in the solution of gold. Possibly both of the conditions just mentioned may in the last analysis be identical. The essential point is that the atomic chlorine in a state of molecular exchange or evolution is able to combine with the gold. For present purposes the gold may be considered to dissolve as gold chloride, although chemical investigations favor the theory that a complex ion containing gold is formed. The only consideration which becomes important in its geological aspect is the presence of the compounds which not only

admit of easy changes of valence, but which act upon hydrochloric acid with the production of free chlorine.

In mine waters chlorine is supplied as NaCl.

16*b*. $Fe_2(SO_4)_3 + H_2SO_4 + NaCl + MnO_2 + Au.$
N/10 N/10 N/25 1 gm. 0.15 gm.

0.00505 gm. loss of gold by solution in 14 days (cold).

Under the same conditions without manganese there was no weighable loss (see experiment 16*a*).

As used herein the normal solution contains 1 gm.-equivalent of the solute in 1 liter of solution. A solution normal with respect to chlorine contains 1 gm. of chlorine times 35.45, the molecular weight of chlorine, in 1 liter of solution.

In this experiment the concentration of Cl (1,418 parts per million) is not so great as has been observed in a few mine waters, and not more than three times as great as Don determined in waters from a number of Australasian mines.[1]

Manganese is abundant in many gold-bearing deposits; is sparingly represented in some; and from a very large number it has not been reported. The chief primary minerals are the carbonates (rhodochrosite and manganiferous calcite), the silicate (rhodonite), amethystine quartz, and the less-abundant sulphide, alabandite. Some rock-making minerals carry small amounts of manganese. It readily forms sulphates, chlorides, etc., and is dissolved by acid mine waters. Manganese changes its valence more readily than other elements common in gold ores.

Lead oxides.—Lead oxide is said to facilitate the solution of gold[2] when added to solutions of ferric sulphate and sodium chloride. Lead is both bivalent and quadrivalent and forms corresponding oxides and hydroxides. These, however, are generally not abundant in the oxidized zones of lead-bearing ore deposits, because the lead carbonate and the sulphate are relatively insoluble in water and usually are formed instead of the oxides. Lead is reported in but one of the 29 analyses of waters from gold and

[1] *Trans.*, XXVII, 654 (1897).

[2] Victor Lehner, *Journal of the American Chemical Society*, XXVI, No. 5, 552 (May, 1904).

silver mines, tabulated above. It is believed to be of very subordinate importance in connection with the solution of gold.

The efficiency of ferric iron and cupric copper to supply nascent chlorine, compared with that of manganitic manganese.—Solutions of ferric sulphate with sulphuric acid and salt dissolve gold at high temperatures. Concentrated solutions of ferric sulphate and hydrochloric acid dissolve gold at from 38° to 43° C. In the cold the reaction may go on in concentrated solutions, but in those approximating the concentration of mine waters no weighable loss of gold was obtained. With MnO_2 under the same conditions there was a very appreciable loss in a solution containing only 1.4 gm. of Cl in a liter. It appears, therefore, that the action of ferric iron on gold in cold dilute mine waters with H_2SO_4 and NaCl is probably negligible; for the experiments with ferric iron in such solutions, without manganese, extended over a period of 34 days without weighable loss of gold.

Many auriferous deposits contain copper, but since the reactions which give nascent chlorine are conditioned upon the presence of some element that changes its valence in the reactions, and since the processes underground take place in sulphate solutions, it did not appear necessary, after ferric salt had been shown to be incompetent, to conduct experiments with copper; for, as is well known, cuprous salts have never been detected in acid sulphate mine waters, whereas ferric and ferrous sulphate are very common in such waters. It has been shown[1] however that the efficiency of cupric salt in cold solution compared with that of manganitic salt probably lies somewhere between 0.004 and 0.000001.

Amount of chlorine necessary for the solution of gold with manganese compounds present.—In experiment 15 (*a*), with MnO_2, 0.01640 gm. of gold was dissolved in 34 days with solution one-tenth normal with respect to chlorine. A solution with but 40 per cent as much Cl (experiment 16*b*) dissolved 31 per cent as much gold in 14 days as was dissolved in the more concentrated solution in 34 days. These results show that in 15 (*a*) conditions are probably approaching equilibrium, and also that the solvent power of chlorine is approximately proportional to the amount present.

[1] *Bull. Amer. Inst. Mining Eng.*, 790 (October, 1910).

That a weighable quantity of gold is dissolved when only a trace of chlorine is present is shown by experiment 13 (*b*), in which chlorine was introduced without intention.

The precipitation of gold.—In igneous rocks ferrous sulphate is the chief precipitating agent. Ferrous sulphate is formed by the oxidation of pyrite, but in the presence of oxygen and H_2SO_4 it becomes ferric sulphate, which does not precipitate gold. Below the water-table, where pyrite is more abundant and free oxygen less abundant, ferrous sulphate may persist in the mine waters. Ferrous sulphate is so effective as a precipitant of gold that it is used for that purpose in metallurgical processes. Experiment 19 shows that a minute amount of ferrous sulphate greatly decreases the solubility of gold, although it does not precipitate it completely. With excess of ferrous salt practically all of the gold is precipitated.

Ferrous sulphate is formed in the upper part of a lode above the water-table; but owing to the open condition of that part of the lode, air is freely admitted and ferric sulphate forms, at the expense of ferrous sulphate and sulphuric acid. This reaction takes place almost instantaneously if MnO_2 is present (experiment 20), for ferrous sulphate and manganese dioxide are under these conditions incompatible. *Manganese dioxide then not only releases the solvent for gold, but eliminates the salt which precipitates it.* It is doubtful whether appreciable amounts of gold are ever carried far below the water-table in mines where the waters carry ferrous sulphate, but, in the presence of MnO_2, ferrous sulphate may be eliminated below the water-table.

When manganese dioxide takes part in the reactions by which, under the conditions named, gold is dissolved, transported, and precipitated, the manganese salt is itself changed. At the surface pyrolusite, MnO_2, forms, for there the excess of oxygen prevails; and this mineral is commonly found in the gossan of manganiferous lodes. When solutions containing H_2SO_4 and NaCl react on MnO_2 there is a tendency to form $MnSO_4$, and some manganese goes into solution as sulphate, but salts of manganese with higher valence may also form. In this connection Dr. R. C. Wells has offered the following statement:

In an acid solution containing some free chlorine, such as has been assumed to be effective in dissolving gold, there would also be a tendency towards the formation of permanganic acid. On the other hand, the production of the chlorine necessarily results in the reduction of the manganese compound. Now a manganous salt is known to react with permanganate to reproduce MnO_2 and this illustrates the tendency of manganese to pass with ease from one stage of oxidation to another. The precipitation of manganese will occur more and more as the solution loses its acidity. It is well established that manganous salts in an acid environment are very stable; but in neutral or alkaline solutions they oxidize more vigorously, one stage of their oxidation being the manganic salt which hydrolyzes into $Mn_2O_3 \cdot H_2O$ (manganite), with even greater ease than ferric salts into limonite.

In these ways the migration of an acidic solution would result in the transportation of both gold and manganese. But in a region of basic, alkaline, and reducing environment the manganese would be reprecipitated, the free acid neutralized, the chlorine absorbed by the bases and removed, and owing to the accumulation of the ferrous or other reducing salts, the gold would be reprecipitated.

V. THE TRANSFER OF GOLD IN COLD SOLUTIONS

1. *Restatement of the processes as related to secondary enrichment.* —Every theory of secondary enrichment of the metals consists essentially of three parts: (*a*) solution, (*b*) transportation, (*c*) precipitation.

a) As already stated, there is in the upper part of the ore deposit, where oxidation prevails, abundance of ferric sulphate and sulphuric acid. A little salt, NaCl, or other chloride, is generally present. The H_2SO_4, reacting upon NaCl, gives HCl, which in the presence of MnO_2 gives nascent chlorine, which dissolves gold. Some manganese goes into solution as sulphate, but certain higher manganates are possibly formed as well.

b) This chemical system will move downward under hydrostatic head. If it comes into a zone containing pyrite it will react upon the pyrite, and in the oxidation of the latter more iron sulphates and acid will be formed. If manganese dioxide is present, or if permanganic acid has been formed, no gold will be precipitated, and the system, with gold still in solution, will move to greater depths before ferrous sulphate can become effective.

c) But as the system moves downward, where no new sources of oxygen are available, the excess of acid is removed. There are

many ways by which acidity is reduced along with these reactions, but the principal one is probably the kaolinization of sericite and feldspar. In these reactions sodium, potassium, calcium, magnesium, and other sulphates are formed from acid and silicates; the silica remaining as SiO_2 and kaolin; the alkalies and alkalic earth sulphates going into solution. As the acidity decreases, iron and manganese compounds tend to hydrolyze and deposit oxides. At this stage of oxidation $FeSO_4$ becomes increasingly prominent, and not only completely inhibits further solution of gold but becomes increasingly effective as a precipitant. Thus manganite is probably precipitated with gold. The fractures in the primary pyritic gold ore below the water level thus become coated with a manganiferous gold ore, which may be very rich. The excess of oxygen which the system has carried down is used up in the manner indicated, and in this process limonite is formed, consequently the manganiferous gold ore deposited in the fissures and cracks contains kaolin and iron as well as manganese oxides.

2. *The oscillating, descending, undulatory water-table.*—The terms "water-table" and "level of ground-water" are generally used to describe the upper limit of the zone in which the openings in rocks are filled with water. This upper limit of the zone of saturation is not a plane, but a warped surface. It follows in general the topography of the country, but is less accentuated. It is not so deep below a valley as below a hill, but it rises with the country toward the hilltop and in general is higher there than in the valley. Nor is it stationary. In dry years it is deeper than in wet years, and in dry seasons it is deeper than in wet seasons. The difference of elevation between the top of this zone in a wet year and in a dry year is normally greater under the hilltop than on the slopes and in the valleys. In mines where the ground is open the level of ground-water probably changes with every considerable rain. Consequently, there is a zone above ground-water in dry periods but below it in wet periods, and in hilly countries this may be of considerable vertical extent. Thus the water-table oscillates, though in general moving downward with degradation of the land surface. It is in this zone of oscillation of the water-table that chemical activity is most varied. Without any change

in the character of the drainage or of the more constant conditions controlling the water-circulation, the chemical composition of the solutions affecting this zone may change from season to season. They may at one time be ferric sulphate or oxidizing waters, and at another time ferrous sulphate or reducing waters, since, after a wet season, the ferrous sulphate waters from below would tend to rise, after dilution with fresh water added by the rains. Consequently, the minerals of this zone may include, besides the residual primary and secondary sulphides, the oxides, native metals, chlorides, etc. Between the top of this zone and the surface or the apex of the deposit chemical activity is probably slow, because there is a scarcity of sulphides and other easily altered minerals to supply the salts upon which the chemical activity of groundwater in a large measure depends. As the country is eroded, this zone also descends; and if a mineral or metal persists long enough, the upper limit of the zone of active change passes below it, and may ultimately be exposed at the outcrop.

3. *The several successive zones in depth.*—As shown by S. F. Emmons, W. H. Weed, and others, many lodes, when followed from the surface down the dip, show characteristic changes. Below the outcrop, the upper part of the oxidized portion of the lode may be poor. Below this there may be rich oxidized ores; still farther down, rich sulphide ores; and below the rich sulphides, ore of relatively low grade. Such ore is commonly assumed to be the primary ore, from which the various kinds of ore above have been derived. The several types of ore have a rude zonal arrangement, the so-called "zones" being, like the water-table, undulatory. They are related broadly to the surface and to the hydrostatic level, but are often much more irregular than either; for they depend in large measure on the local fracturing in the lode which controls the circulation of underground waters. Any zone may be thick at one place and thin, or absent, at another. If these zones are platted on a longitudinal vertical projection, it is seen that the primary sulphide ore may project upward far into the zone of secondary sulphides, or into the zone of enriched oxides, or into the zone of leached oxides, or may even be exposed at the surface. The zone of secondary sulphide enrichment (which is

not everywhere present) may project upward far into the zone of rich oxidized ore, or into the zone of leached oxides, or may outcrop at the surface. The zone of sulphide enrichment nearly always contains considerable primary ore, and very often the secondary ore is merely the primary ore containing in its fractures small seams of rich minerals. The zone of enriched oxides is generally found above the water-table when the latter is at the lowest, and often extends to the outcrop. In regions of rapid erosion, and especially of rugged topography, the conditions for the exposure of rich oxides, or even rich sulphides or primary ore, are more favorable. In places along the outcrop of a deposit where erosion is rapid the richer oxidized or sulphide ores may be exposed, whereas in other places, protected from erosion, and therefore exposed longer to solution, the same outcrop is frequently leached. It is evident that the amount of metal remaining in the upper part of the oxidized zone and at the outcrop depends upon the ratio between the rate at which the metal is dissolved, and the rate at which the valueless constituents are dissolved and removed. Under certain conditions gold is removed very slowly, and the removal of valueless constituents may effect a concentration at the very apex of the lode; while under other conditions, favorable to the solution of gold, it is removed more rapidly than silica, iron, etc., and the apex and the oxidized zone are leached. In a country not subject to erosion it would be supposed that the outcrops of manganiferous lodes would be everywhere leached; but rapid erosion may remove the upper part of the lode before it is completely leached, and, under favorable conditions, placers accumulate from the débris of the apex.

It thus appears that all of these zones except that of the primary ore are continually descending; so that ore taken from the outcrop may represent what was once primary ore; afterward, enriched sulphide ore; still later, oxidized enriched sulphide ore; later still, leached oxidized enriched sulphide ore; and finally become the surface ore. Through more rapid erosion at some particular part of the lode, any one of these zones may be exposed; and hence an outcrop ore of any character is possible. Consequently, longitudinal assay plans, showing the changes of value

in depth, though highly suggestive, and especially so when gold and silver are shown separately, are supplemented by studies of the paragenesis and by physiographic studies, in order that the approximate rate of erosion of the lode at various places may be known. In the absence of such knowledge, it is generally impossible to tell the genesis of a particular sample of ore from a mine. When all the data are assembled, however, greater confidence may be placed in the conclusion, since all the factors in the problem are intimately related.

4. *Criteria for the recognition of secondary enrichment.*—I shall not attempt to review all the criteria for the recognition of secondary enrichment. They involve practically all available data relating to the geology and physiography of a region, as well as the observed characteristics of its ore deposits. But each group of deposits may be studied with certain general criteria in view. Among these are: (1) the vertical distribution of the richer portions of the lode with respect to the present surface and to the level of ground-water; (2) the mineralogy of the richer and poorer portions of the deposit, and the character and vertical distribution of the component minerals; (3) the paragenesis, or the structural relations shown by the earlier ore and that which has been introduced subsequently.

In applying these principles, it should be remembered that circulation is generally controlled by post-mineral fracturing; that the changes depend upon climate and rapidity of erosion, and are affected by regional changes of climate, etc. Although the mineralogy of the ore is a useful aid, there are many minerals which are precipitated from cold solution and also from ascending hot solutions, and there are many others, the genesis of which is uncertain. Of the minerals formed in the zone of secondary sulphide enrichment, few, if any, are known positively to form under such conditions only. There are some, however, such as chalcocite and covellite, which nearly everywhere are clearly of secondary origin. Ruby silver is frequently, but not always, secondary. Other minerals, such as chalcopyrite, bornite, argentite, etc., have no definite indicative value unless their occurrence suggests that they are later than the primary ore. Where minerals,

known to have formed elsewhere by processes of secondary sulphide enrichment, are clearly later than primary ore, there is a strong presumption that they were deposited by cold descending waters. If it can be shown, in addition, that they do not extend to the bottom of the mine, but are related to the present topography of the country, then this presumption may be regarded with considerable confidence as confirmed.

With respect to gold, the problem is difficult, because the native metal is the only stable gold mineral known to be deposited from cold dilute solutions. Consequently, the applicable criteria are limited; and the vertical distribution of the richer ore, though suggestive, is not in itself conclusive. Lindgren and Ransome, in their studies at Cripple Creek, have shown that the richer ore bodies may have in general a relationship to elevation, where there is little or no evidence of deep-seated secondary enrichment. The maximum deposition by ascending hot waters may be greater at one horizon than at another; and the rich ore, though showing broadly certain variations with depth, is in no way related to the water-table. If, however, it can be shown that rich seams of ore cross the primary ore and do not extend downward as far as the lowest level in the primary ore, but are related to the present topography of the country, and if it is known that the associated minerals which fill such openings are those which may be deposited by cold waters, the evidence of their secondary origin is practically conclusive. As already shown, seams of gold with limonite and manganese oxides occur in such relations. Similar ore frequently contains chalcocite and argentite also. Such occurrences could with great confidence be attributed to descending waters.

In the practical application of such reasoning to gold-bearing deposits it will sometimes be necessary to discriminate between the oxidized manganiferous gold ore which has resulted simply from the oxidation of a primary manganiferous ore like one containing rhodochrosite, and that which has been deposited in fractures in the sulphides lower down. In other words, it is desirable to know whether rich manganiferous ore in the upper part of a mine is residual from a primary ore body, and there-

fore will probably prove extensive, or represents the result of concentration under more deeply seated conditions after the manner indicated above. This discrimination may be easy in the sulphide zone, where the fractures with rich manganiferous ore are clearly shown; but in the oxidized zone one must rely upon the shape and distribution of the richer portions. If they are related to cracks in the mass of the oxidized ore, the inference is warranted, in the absence of other evidence, that they are residual secondary ore, and, being genetically related to the present topographic surface, are limited.

Native gold is, as already stated, the only gold mineral which is deposited by cold solutions. But native gold is deposited by primary processes also, and is by far the most abundant gold mineral so deposited. Consequently, in distinguishing between primary gold and gold deposited by cold solutions, one must rely upon associated minerals. When secondary chalcocite or certain secondary silver minerals are deposited, the attendant reactions precipitate gold. Consequently, the richer bunches of gold ore in the oxidized zone, residual from secondary ore formed under the deeper-seated conditions, may carry also considerably more copper and silver than the primary ore. But copper, and (unless cerargyrite is formed) silver also, are more readily leached than gold, even when manganese is present. Hence, the evidence of this character may have been destroyed.

With respect to other minerals associated with the secondary gold ore, we are not warranted, in the present state of our knowledge, in drawing definite conclusions. From the nature of the reactions, I think it may be possible to show that manganite, $Mn_2O_3 \cdot H_2O$, is, under conditions of incomplete oxidation, more often associated with the rich gold in such relations than pyrolusite, MnO_2; for, as already observed, the lower oxide is more likely to be precipitated than the higher, when secondary gold is deposited under deep-seated conditions. But under oxidizing influences the manganese oxides change their character so readily that this criterion, if it has any value, is probably not applicable to ores in the upper part of the oxidized zone, where they have been exposed to more highly oxygenated waters for a longer time. I

make these suggestions with respect to the character of the manganese oxides associated with the rich ore, not because I think the reactions which precipitate manganese are well enough understood to give a positive paragenetic value to the oxidized manganese minerals themselves, but in the hope that others will ascertain and report the character of the manganese oxide associated with gold in the deeper zone and in the residual products from that zone.

5. *Lateral migration of manganese salts from the country rock to the ore.*—Clarke's analyses[1] show that igneous rocks carry an average of 0.1 per cent of manganese oxide, and many basic rocks carry from 0.2 to 0.9 per cent. Where basic dikes have cut an ore body, they doubtless contribute manganese to the waters circulating in the deposit. The ore of the Haile mine, in South Carolina, is cut by basic rocks; and the ore bodies of the Delamar mine, in Nevada, are crosssed by a basic dike. Both of these deposits show secondary enrichment of gold; and in both the better ore is found along the dikes. In general, however, the manganese from the country rock cannot safely be assumed to have migrated extensively into the ore deposit, for many analyses of mine waters do not show manganese; but where manganiferous rocks are intimately fractured and filled with seams of ore it would be supposed that the reactions requiring manganese could take place.

In my own experience I have found only trivial stains of manganese in those lodes where it was not present in the gangue of the primary ore; and, in view of its wide distribution in igneous rocks, I believe that the lateral migration of manganese into the ore under the conditions which generally prevail is very subordinate. Though the amount so contributed may facilitate the solution of gold, it is probably inadequate to form sufficient higher manganates or similar salts to suppress effectively the action of ferrous sulphate. Under such conditions the gold could not travel to the reducing-zone below the water level, but would be precipitated practically at the place where it had been dissolved.

6. *Concentration in the oxidized zone.*—The concentration of gold in the oxidized zone near the surface, where the waters

[1] *Bulletin No. 330, U.S. Geological Survey* (1908).

remove the valueless elements more rapidly than gold, is fully treated by T. A. Rickard in his paper on the "Bonanzas in Gold Veins."[1] Undoubtedly this is an important process in lodes which do not contain manganese, or in manganiferous lodes in areas where the waters do not contain appreciable chloride. In the oxidized zone it is sometimes difficult to distinguish the ore which has been enriched by this process from ore which has been enriched lower down by the solution and precipitation of gold, and which, as a result of erosion, is now nearer the surface. It cannot be denied that fine gold migrates downward in suspension; but in all probability this process does not operate to an important extent in the deeper part of the oxidized zone. If the enrichment in gold is due simply to the removal of other constituents, it is important to consider the volume- and mass-relations before and after enrichment, and to compare them with the present values. In some cases, it can be shown that the enriched ore occupies in the lode about the same space as was occupied before oxidation. Let it be supposed that a pyritic gold ore has been altered to a limonite gold ore, and that gold has neither been removed nor added. Limonite (sp. gr. from 3.6 to 4), if it is pseudomorphic after pyrite (sp. gr. from 4.95 to 5.10) and if not more cellular, weighs about 75 per cent as much as the pyrite. In those specimens which I have broken, cellular spaces occupy in general about 10 per cent of the volume of the pseudomorph. With no gold added, the ore should not be more than twice as rich as the primary ore, even if a large factor is introduced to allow for SiO_2 removed and for such cellular spaces.

Rich bunches of ore are much more common in the oxidized zone than in the primary sulphides of such lodes. They are present in some lodes which carry little or no manganese in the gangue, and which below the water level show no deposition of gold by descending solutions. Some of them are doubtless residual pockets of rich ore which were richer than the main ore body when deposited as sulphides, but others are doubtless ores to which gold has been added in the process of oxidation near the water-table by the solution and precipitation of gold in the presence of the

[1] *Trans.*, XXXI, 198–220 (1901).

small amount of manganese contributed by the country rock. In view of the relations shown by the chemical experiments it is probable that a very little manganese will accomplish the solution of gold, but that it requires considerably more manganese to form appreciable amounts of the higher manganese compounds which delay the deposition of gold, suppressing its precipitation by ferrous sulphate. In the absence of larger amounts of the higher manganese compounds, the gold would probably be precipitated almost as soon as the solutions encountered the zone where any considerable amount of pyrite was exposed in the partly oxidized ore. From this it follows that deposits showing only traces of manganese, presumably supplied from the country rock, are not enriched far below the zone of oxidation.

7. *Vertical relation of deep-seated enrichment in gold to chalcocitization.*—In several of the great copper districts of the West gold is a by-product of considerable value. In another group of deposits, mainly of middle or late Tertiary age and younger than the copper deposits, silver and gold are the principal metals, and copper, when present, is only a by-product. But in some of these precious-metal ores chalcocite is, nevertheless, the most abundant metallic mineral, often constituting 2 or 3 per cent of the vein matter. Frequently it forms a coating over pyrite or other minerals. Some of this ore, appearing in general not far below the water-table, is fractured, spongy quartz, coated with pulverulent chalcocite. It frequently contains good values in silver, and more gold than the oxidized ore or the deeper-seated sulphide ore. Clearly, the conditions which favor chalcocitization are favorable also to the precipitation of silver and gold.

The exact chemical reaction which yields chalcocite is not known. At 100° C., according to Dr. H. N. Stokes,[1] the reaction with pyrite is probably about as follows:

$$5FeS_2+14CuSO_4+12H_2O=7Cu_2S+5FeSO_4+12H_2SO_4.$$

In the cold, the reaction may differ in details, but without doubt much ferrous and acid sulphate is set free. Attendant reactions

[1] Unpublished MSS quoted by Lindgren in *Professional Paper No. 43, U.S. Geological Survey,* 183 (1905), and in Weed's translation of Beck's textbook.

confirm this statement; for, if calcite is present, gypsum is formed by the reaction of H_2SO_4 on lime carbonate; and, if the wall-rocks are sericitic, kaolin is formed by the acid reacting upon silicates, the potash going into solution as sulphate. The abundant ferrous sulphate must quickly drive the gold from solution, and it apparently follows that there may be no appreciable enrichment of gold below the zone where chalcocitization is the prevailing process.

VI. REVIEW OF MINING DISTRICTS

1. If gold is more readily dissolved in manganiferous deposits, it would be supposed that placers form less readily from pyritic manganiferous lodes than from lodes containing no manganese. If, in areas where the waters carry appreciable chlorine, placers have formed as extensively from such lodes as from lodes free from manganese, then the hypothesis fails.

2. The manganiferous lodes, in areas of chloride waters, as in the undrained areas of the Great Basin, should in general show less gold at the outcrop and in the upper portion of the oxidized zone than below. In silver-gold deposits, however, silver, on account of the insolubility of the chloride, may remain, or be concentrated, in the oxidized manganiferous zone. Bunches of rich gold ore carrying oxidized manganese in the oxidized zone are not necesssarily fatal to the theory; for, as already stated, these are probably residual from the zone of secondary enrichment. An extensive enrichment in gold of the oxidized manganiferous ores at the surface, which are shown not to be residual from the zone of secondary ores, would indicate that the selective processes lack quantitative value, if the waters carry chlorine, and if the primary ores, from which the manganiferous oxidized ores are derived, carry appreciable pyrite to supply sulphate.

3. If in certain lodes gold migrates below the water-table, it should be precipitated quickly by ferrous sulphate. But MnO_2 converts ferrous sulphate to ferric sulphate, which does not precipitate gold. Hence, MnO_2 favors the solution of gold, and converting the ferrous salt to ferric sulphate removes the precipitant. Consequently, if auriferous lodes show enrichment in

the deeper zone but related to the present surface of the country, the manganiferous lodes should, the other favorable conditions provided, show greater differences in values with respect to gold than lodes free from manganese.

Gold provinces of the United States.—As Lindgren[1] pointed out in 1902, the principal gold deposits of the United States may be divided into four groups. The deposits of each group belong mainly to one metallogenetic epoch, and certain relationships are clearly shown. This classification, which has thrown much light on the genesis of the deposits, is useful as an instrument for study and for comparison of the deposits with respect to the problem of the migration of gold in them.

1. The Appalachian gold deposits, and those of the Homestake type in South Dakota, are the most important representatives of the oldest group. These deposits generally yield placers, are usually low grade below the water level, and are singularly free from bonanzas. They are, in general, not greatly leached near the surface, and may have been enriched by the removal of other material more rapidly than gold. At only one of them, the Haile mine, in South Carolina, it is thought probable that gold has been carried below the water level. Judging from descriptions, practically all of these deposits are free from manganese.

2. The California gold veins and related deposits in Nevada (Silver Peak) and in Alaska (Treadwell, etc.) are younger than the Appalachian deposits, and were probably formed in the main in early Cretaceous times. These deposits, where physiographic conditions are favorable, have generally yielded rich placers. At many places, moreover, the ore is worked at the very surface, and, there is very little evidence of the migration of gold to the deeper zones. In the places where detailed work has been done, rhodochrosite is never a gangue mineral, although manganese oxide does occur in traces in the country rock, and rhodochrosite is found in a few places in veinlets in the mining districts but not associated with the gold veins.

3. The deposits of the third group are later than the early

[1] "The Gold Production of North America," *Trans.*, XXXIII, 790–845 (1903); "Metallogenetic Epochs," *Economic Geology*, IV, No. 5, 409–20 (Aug., 1909).

Cretaceous, and some of them are probably early Tertiary. They are extensively developed in Montana, Nevada, Utah, and Colorado. Mr. Lindgren calls this group the Central Belt. Many of its deposits have yielded considerable gold, and in certain other districts very closely related genetically (Butte, Georgetown silver-gold lodes, Cortez Nevada, Tintic, etc.) much gold has been obtained as a by-product to copper or silver mining. Some of these deposits have yielded placers and some have not. At Philipsburg and Neihart, Mont., Georgetown, Colo., and elsewhere, the deposits show a secondary enrichment of silver below the water-table. At Philipsburg, and probably at some other places, an enrichment in gold accompanies this concentration of silver. Some of the lodes of group 3 carry much manganese, and some carry none. Present data are meager for most of these districts. The determination of gold from the surface down in a large number of deposits would serve as a useful check to the conclusions based upon the chemistry of the processes involved in its solution and precipitation.

4. Group 4 includes the most recent ore deposits in the United States. All of them are Tertiary, and most of them are Miocene or Pliocene. In general, they were formed relatively near the surface, and in some places it is highly probable that not more than a thousand feet of vein material has been removed by erosion since the ores were deposited. The majority of these deposits carry silver, and in many of them its value is greater than that of the gold; but they have supplied, notwithstanding, about 25 per cent of the gold production of North America. They are typically developed in Nevada (Comstock, Tonopah, Goldfield, Tuscarora, Gold Circle); California (Bodie); Idaho (De Lamar); South Dakota (later than Homestake type); Colorado (Cripple Creek, Idaho Springs, Rosita Hills, San Juan, etc.); Montana (Little Rockies, Kendall, etc.). Many occurrences in Mexico should probably be placed here, also. The deposits of this group have not supplied much placer gold. Many of these deposits are in arid countries, where conditions for working placers are not favorable; but even those in well-watered districts supply relatively little placer gold. Manganese is abundant in some of

these deposits (Comstock, Exposed Treasure, Tonopah); it is very sparingly present in others (Little Rockies); in still others (Goldfield) it is almost entirely absent.

A few small placers are associated with the manganiferous lodes, although at some places they seem to have been derived from veins near by which are not manganiferous. Many of the California veins carry rich ore at the very surface, but the Tertiary gold veins are generally richer in gold a few feet below the surface than at the outcrop. Doubtless, many of them would have been overlooked if it had not been for the concentration of horn silver and argentiferous pyromorphite at the surface.

It thus appears that practically all of the manganiferous gold deposits of the United States, so far as they have been described, may be included in groups 3 and 4; that nearly all described deposits where relations indicate a migration of gold belong to the same groups; that placers are much less abundantly developed than in groups 1 and 2; and that outcrops less frequently supply gold; that secondary enrichment below the water-table, if carried on at all, proceeds with extreme slowness in groups 1 and 2, but may be more pronounced in deposits of groups 3 and 4. Not all deposits of 3 and 4 carry manganese, however, and those which do not carry it show relationships more nearly approximating those which hold in the California gold veins. The migration of gold in the more important auriferous deposits of the United States is discussed in some detail in *Bull. 46, Amer. Inst. Mining Engineers*, 817–37.

LOCAL DECOMPOSITION OF ROCK BY THE CORROSIVE ACTION OF PRE-GLACIAL PEAT-BOGS

EDWIN W. HUMPHREYS AND ALEXIS A. JULIEN

While the layer of decayed rock which once overlay the region around New York City has been generally planed off by the continental glacier, certain small isolated spots have been noted from time to time in which masses of rotten schist still remain. Their decay is commonly attributed to weathering action, and their escape from the glacial scour at such points, to their probable protection by projecting eminences of rock under whose lee they are supposed to lie.

Excavation in schist.—An unusually large occurrence of this kind has been recently exposed in an excavation for a cellar on the east side of the junction of Southern Boulevard and Westchester Avenue, Borough of the Bronx, New York City, whose general form and dimensions[1] are shown in Fig. 1.

The gneissic schists here present the foliation with usual high angle, 70° to 90°; strike N. 23° E. and S. 23° W. A small anticlinal fold crosses the strata, as shown in the diagram (Fig. 1) whose axis runs N. 52° E. and S. 52° W. A small overthrow is shown in its cross-section at the northern end, and at its southern end it pitches to the southwest at an angle of about 30°. The rock consists chiefly of a fine granular aggregate of quartz, with much biotite in minute black scales, and more or less disseminated white feldspar. Throughout the western half of the excavation, however, many thin seams of pegmatitic gneiss and of gray quartz are intercalated, up to nine inches in thickness.

Pegmatite dike.—A pegmatite dike, about five feet in width, nearly vertical, also cuts obliquely through the schists, with a course of N. 30° E. and S. 30° W. At many points, small projections or apophyses branch out into the schist along its course and are,

[1] We wish to express our indebtedness for these data to Mr. C. S. Shumway, superintendent of the Construction Department of the American Real Estate Co.

apparently, connected with some of the pegmatitic seams intercalated in the schist. The position of the dike, on the west side of the overthrow in the anticline at the north end, suggests that it has there acted as an obstacle against the northwestward thrust of the beds and so produced the westward distortion of the upper side of the fold. The pegmatite itself is an aggregate of grayish quartz, white feldspar, and very little mica, of the rather uniform medium texture usual in the dikes of the Bronx region, with grains rarely exceeding two or three inches.

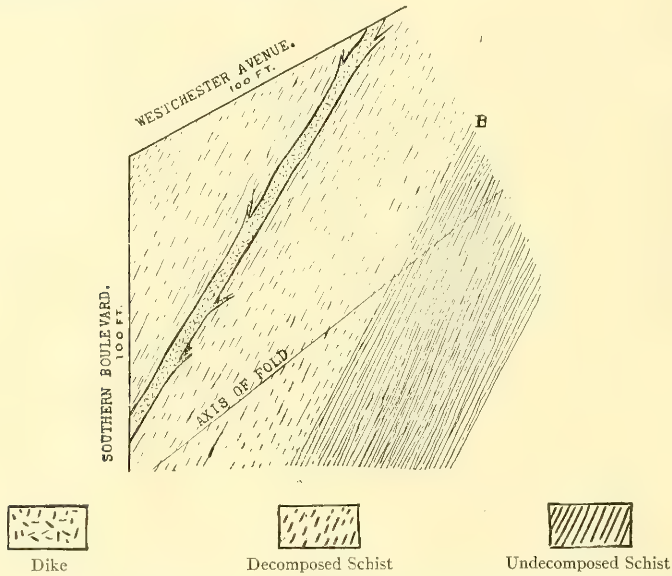

FIG. 1.—Relative positions of decomposed schist, undecomposed schist, and pegmatite dike.

Decay of schist.—In the eastern part of the excavation, the rock was hard and sound, and needed to be blasted for removal. In the western, the schist was thoroughly decomposed throughout to an undetermined depth, so soft that it was easily removed with pick and shovel, bluish to purple gray in color, and in texture passing from a gritty aggregate almost to a clay; the latter corresponded closely to the glacial clays of similar color commonly found about the city. The two tracts, fresh and decayed, were separated by an exceedingly sharp contact (the line A–B in the diagram), so that,

in the cross-section at the north end (at the point B), the hand placed across this line would rest on the left upon the decomposed schist, easily dislodged by the touch of a finger, and on the right upon the hard fresh rock. This contact is shown in Fig. 2, with the decayed schist on the left, and on the right the same rock in rugged, hard condition. The trend of this sharp division line was N. 28° E. and S. 28° W., approximately parallel to the course of the dike. However, in the cross-section, a few seams of decayed rock were noticed to the east of this line, descending a yard or more into the solid schist. The same section showed that the upper eroded surface of the schist descended from a height of fourteen feet at the point B along the northeast wall, to a height of seven and one-half feet, in a distance of fifty-four feet to the corner on Westchester Avenue.

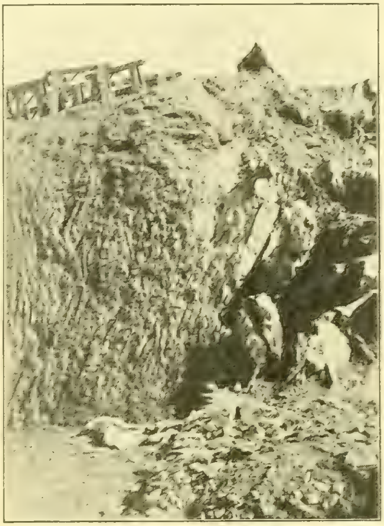

FIG. 2.—Contact of decomposed and undecomposed schist.

Decay of pegmatite.—A similar decay has affected the pegmatite, much of whose feldspar has passed into a white kaolinic clay, so that this rock also was easily removed by means of the pick. Although it is even now much more tough and solid than the surrounding schist, it appears to have been planed off by the ice at about the same level, as shown near the bottom of the cross-section (Fig. 3) where the north end of the dike strikes the wall at Westchester Avenue. Above it lies a layer of till, and then a slab of granitic gneiss. It should be also noted that the decay above described is entirely exceptional in this region. For example, in another excavation in the schist, a few hundred feet to the north, the same schist was found practically undecomposed and sound. So also as to the numerous other pegmatite dikes in the Bronx, all we have observed are solid and show almost no decay.

Glacial deposits.—The layer of glacial deposits, which overlies the schist at this locality, as shown in the following generalized cross-section along Westchester Avenue (Fig. 4), about fifteen feet from the street level to the greatest depth in the excavation, is yet to be considered.

	Feet
Fawn-colored micaceous sand with some trap bowlders	3–5
Slab of pegmatitic gneiss	1
Gray sandy till, with striated bowlders	$\frac{1}{2}$
Slab of pegmatitic gneiss	1
Gray till, rich in micaceous clay	$\frac{1}{4}$–$\frac{1}{2}$
Slab of pegmatitic gneiss	$\frac{1}{4}$–$\frac{1}{2}$
Gray bowlder clay	$\frac{1}{2}$–3
Slab of pegmatitic gneiss	$\frac{1}{2}$–$2\frac{1}{2}$
Blue-gray bowlder clay	$\frac{3}{4}$
Slabs of pegmatitic gneiss and Manhattan schist	$1\frac{1}{4}$
Blue-gray bowlder clay	1
Decayed schist in place with vertical foliation, intercalated with thin seams of pegmatite	6–$8\frac{1}{2}$

The remarkable deposit of ground moraine, which here rests upon the upturned edges of the schist, is thus found to consist largely, in the two hundred feet of section exposed along the two avenues, of a succession of huge, overlapping sheets of granitic gneiss separated by layers of sand and till or bowlder clay.

The gneiss slabs, of which a series of from four to eight are shown in any particular part of the section, consist of a rather fine-grained granitoid gneiss of constitution similar to that of the pegmatite. Their dimensions in cross-section vary from about 3 to 35 feet in length, and in thickness from 1 to 30 inches or more. There was no opportunity to determine their real shape, but apparently they consisted of flat sheets, often thinning down toward the edges to an inch or less. Some show fracture and faulting in place, as by the effect of superincumbent pressure (Fig. 5), and occasionally the extension of such a slab toward its edge into a thin pliable sheet, one or two inches thick, reveals a marked curvature as by pressure from above (Fig. 6). Toward the bottom of the section, they may be accompanied by a few small sheets of fine biotitic schist, like that of the underlying rock in place. The granitoid gneiss in these slabs shows partial to thorough decay, so that they

mark the cross-section by a series of conspicuous, white, kaolinic, lenticular bands, contrasting with the intervening layers of dark till.

The bowlder clay of these intervening layers is very dense and compact, sometimes sandy, sometimes rich in mica and clay, and contains few pebbles and occasional bowlders up to about two feet in diameter, which may show sharp, glacial striae. These consist partly of rocks of the vicinity, quartz from seams, granitoid and hornblende gneiss, etc., and partly of rocks from the Palisades on the west bank of the Hudson River, about five miles distant, viz., diabase, coarse red sandstone, indurated shale from the contact underlying the trap, etc. Nearly all these bowlders are hard and undecomposed.

FIG. 3.—Manner in which the pegmatite dike was planed off by the glacier.

FIG. 4.—Section along Westchester Avenue.

At several points where such a trap bowlder rested immediately upon a granite slab, the latter was deeply indented, its folia separating and rising a little around the bowlder, above the upper level of the slab. Immediately

under the bowlder, the folia of the granite showed differentiation and deformation as by a crushing force from above; but the lower level of the slab rarely showed much if any depression in a direction below the bowlder (Figs. 7 and 8).

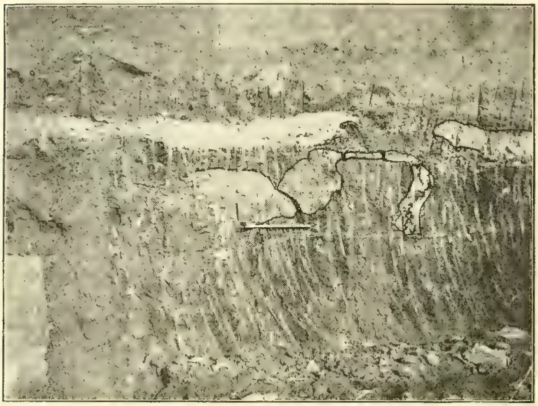

FIG. 5.—Fracture and faulting shown by one of the transported slabs.

Cause of decay.—In seeking to account for this peculiar decomposition in one tract of the schist, the action of the weather is barred out, on account of the absence of such decomposition in adjoining areas of schist, as well as in the other pegmatite dikes of the Bronx region, the absence of concentration of iron oxide from agencies of mere oxidation,[1] and the sharp line of demarkation between this tract and the unchanged schist. All the facts point to some agency which could produce deep local corrosion, and the considerable leaching shown by the removal of iron oxide and by the residues of white kaolin. The presence of the pegmatite dike across the middle of this tract, and its parallelism to the sharply

FIG. 6.—Curvature produced by pressure on a transported slab.

[1] Stremme, *Zts. f. prkt. Geol.*, XVI (1908), 128.

defined border of the decay on the east, at once suggest its possible connection in some way with this chemical action. This might be referred to an attack of the schist by the magmatic vapors, "the post-volcanic gas exhalations" of Weinschenk, accompanying the eruption of a dike of acid constitution, but for the entire absence of such effect in the vicinity of the tourmaline-bearing granite dikes which abound throughout this region. Taking all the facts here observed, we conclude that at this locality we find proofs, in the deep erosion, solution, and leaching, of the long-continued action of humus acids from peat-water, resulting in products which correspond to the "Grauerde" of Germany, studied by Ramann, Wüst, Selle, Stremme, etc.[1] It seems probable that this deep local decay of both gneissic schists and the inclosed pegmatite records the continuous corrosion of an ancient pre-glacial peat-bog. The eastern border of the bog appears to be marked by the sharply defined eastern limit of this decayed tract. The wall of impervious pegmatite may perhaps have formed a dam to confine the corrosive liquids, as in a vat, along this edge of the ancient bog; in such case the limit of corrosion would naturally lie parallel to the line of the dam.

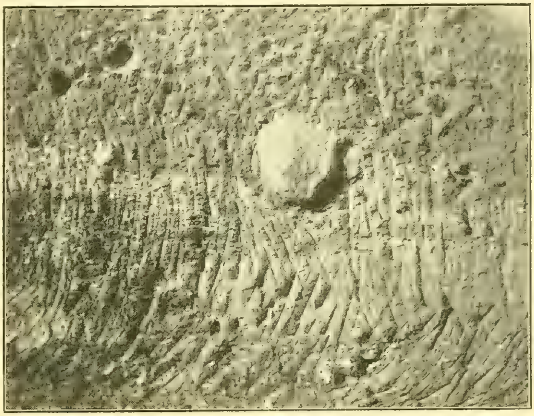

FIG. 7.—Showing how a bowlder was forced into one of the transported slabs.

With the prevalent tendency to attribute the formation of the original layer of laterite over the northern part of our continent mainly or exclusively to weathering by meteoric agencies, there seems to have been little recognition of the view above suggested in explanation of the local instances of deeper decomposition of

[1] H. Rösler, *Zts. f. prkt. Geol.*, XVI (1908), 251–54.

crystalline rocks which have escaped the glacial scouring. It therefore may be added that we find abundant evidence of the wide distribution of tundra and peat-bogs all over this region, for a long period before the advance of the continental glacier as well as since its retreat. In the adjoining region, Westchester County, Mather recorded, sixty years ago, observations on peat-bogs, covering in the aggregate nearly 400 acres. Throughout the Bronx tract, in all directions around the locality we have described, we have noted many remnants of these, in street and house excavations, which have not yet been destroyed by the advances of the great city. These now vary widely in area and in depth. A few instances will be presented to show that this form of chemical corrosion must have been here an active factor in degrading even the elevations of the rock-surface.

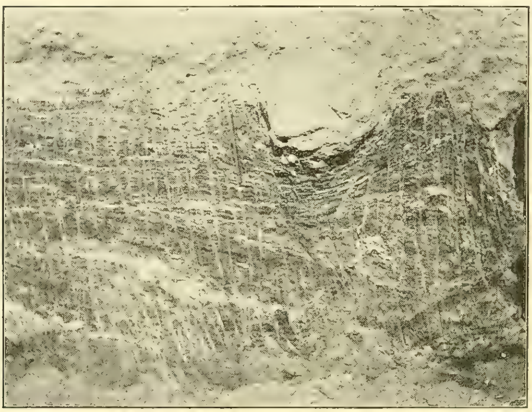

FIG. 8.—Another bowlder that was forced into a slab.

Thus, along the low valley now occupied by Morris Avenue, the depression in the glaciated surface was formerly filled with peat, even now particularly well shown in the vicinity of 170th Street. In filling in this street with rock, the peat was forced up in places to a height of ten feet on each side, and its surface cracked in all directions, revealing pockets of fresh-water shells. Thence the bog certainly stretched for a quarter of a mile, with a width of several hundred feet; while there is evidence of its former extension southward, probably as far as the Harlem River, and northward for an indeterminate, but long, distance. At 178th Street and Honeywell Avenue, a peat-bog yet remains and has recently been partially excavated, of which the original area, we estimate, must have occupied several hundred acres along the low valley. Its depth, as

proved by driven piles, reached, here, twenty-two feet. The bed of this formerly great swamp is now crossed by Daly Avenue, Honeywell Avenue, Southern Boulevard, Mapes Avenue, and Prospect Avenue. At Daly Avenue near Tremont Avenue, the depth of the peat was such that it was found necessary for foundations to drive piles forty-five feet in length. Not only were the lower grounds so filled up, especially the long valley depressions, such as those of the Bronx River, Eastchester Creek, Tibbit's Creek, etc., but thin local sheets seem to have rested in the hollows among the rounded hummocks of the glaciated upland; these are in part still represented by little marshes, or the ponds in the various parks. It appears but a moderate estimate to assert that at least one-third of the surface of this region was once covered by an almost continuous sheet of fresh-water bog, out of which the higher elevations protruded as knobs of forest-covered rock. Along the adjoining coast at Hunt's Point, Bartow, etc., these ancient bogs have been since overlaid, during the subsidence now in progress, by a sheet of salt meadow, surrounding a large number of small scattered islets of now bare outcrops of gneiss and granite.

Further evidence of the early and long activity of organic acids in solution, removal, concentration, and deposit of iron oxide from the surface of these rocks is afforded by numerous accumulations of bog iron ore once found throughout this region as well as over Manhattan Island. Though generally small, some of these were of sufficient volume to be of economic importance and use two hundred years ago.

Escape of decayed schist from removal by the glacier.—There was here no knob or eminence on the northwest for the protection of the softened schists from the scour of the ice moving from that direction. On the contrary, a low valley lies on that side, which we presume was occupied by the peat-bog. The pegmatite itself, though softened, probably served long as the main protection of the schist, in connection with the pegmatitic branches and seams intercalated in the schist in this part of the tract. The next resulting condition was apparently the erosion of this surface of the schist in an inclined plane, tending to lift the edge of the ice-sheet

up to the surface of the solid rock. The last phase appears to have been the plucking-up of huge thin slabs from a mass of thinly foliated granite, somewhere in the valley adjoining on the west, and their deposit as a ground-moraine over this inclined plane, with intervening sheets of bowlder clay, in a kind of natural masonry, for further protection of the underlying soft schists.

Evidences and measure of the superincumbent pressure.—Soft as this granite is now found, it is obvious that it must have possessed much strength and rigidity at the time of its transport by the ice in the form of slabs, mostly from a few inches up to a foot in thickness, although commonly ten to twenty feet or more in greatest extension. The pressure upon them, as well as their rigidity, is shown by the frequent fractures and faulting, and the bending of thin edges. Still more significant is the crushing of the rock within the slabs at the contact with overlying bowlders of trap, which have been pressed down into pockets in the granite. In one case (Fig. 7) the bowlder appears to have been lifted subsequently somewhat out of its pit and the clay forced in beneath it. In another (Fig. 8) the crushed granite rises around the imbedded bowlder, which was eighteen inches in diameter, as if the rock was almost plastic, either on account of the great pressure or of its own softened condition, or both. We had almost hoped to have found here a natural record of the weight of the superincumbent ice, and therefore of its thickness, by estimating the volume of the granite crushed beneath the imbedded portion of the bowlder. This was found impracticable, from the impossibility of determining the crushing strength of the rock at the time of its penetration. However, we already possess some measure of the thickness of the ice-sheet in this region in the presence of glacial striae, often an inch in depth, at points 250 to 300 feet in elevation; e.g., on the edges of the gneiss over the summit of Inwood Heights, Manhattan Island, and on the trap along the edge of the Palisade escarpment, on the west side of the Hudson River. These imply a pressure which could hardly have been exerted by a sheet of ice less than 1,000 feet in thickness.

ON THE FOCUS OF POSTGLACIAL UPLIFT NORTH OF THE GREAT LAKES

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Washington, D.C.

The first determination of the approximate location of the focus of postglacial uplift, based upon the amount of rise found in the beaches about Lake Ontario and Georgian Bay, appeared in a volume, to which access is difficult,[1] and for this reason the passage may be cited, as the revision to be given below will be found in general conformity with the previous conclusions.

> If the axis of maximum elevation for the various triangles about Lake Ontario and Georgian Bay be produced, they meet near latitude 51° N., and longitude 74½° W., a few miles west of Lake Mistassi and east of the southern end of James' Bay. Although mainly radiating from the focus, the axes of maximum elevation for the different triangles are not uniform, and are locally modified, as along the western side of Lake Ontario, where there is found a secondary axis of uplift to the east. Combining the more western axes with those of the eastern end of the lake, another focus of uplift appears near the "Height of Land" between Lake Ontario and Hudson Bay, in about latitude 48° N., and longitude 76° W. From the double foci it may be inferred that the uplift reached its maximum along a line joining the foci, or that the axis of maximum regional uplift was meridional and located along the eastern end of Lake Ontario, increasing in amount until near the "Height of Land," and thence with a diminishing ratio, or even depression, towards the north. . . . At any rate, it is in the region southeast of Hudson Bay that the maximum differential elevation of the earth's crust, which involved the Iroquois beach, is to be found.[2]

Since that time (1889), Gilbert, De Geer, Taylor, and recently Goldthwaite have illustrated more or less fully the rise by isobars, which is only another mode of expressing the same phenomena, while Coleman has redetermined some of the triangles.

Combining additional measurements obtained from Fairchild and Goldthwaite, I have recalculated the mean rise in the various triangles from the present heights of the beaches about Lake

[1] *Transactions of the Royal Society of Canada*, VII, sec. iv, 189, read May 5, 1889.

[2] J. W. Spencer, *ibid.*, 189.

Ontario and Georgian Bay, The postglacial bulge is like a sheet raised by an object thrust under it, the height increasing from outward from the focus of rise, but we can differentiate it in triangles

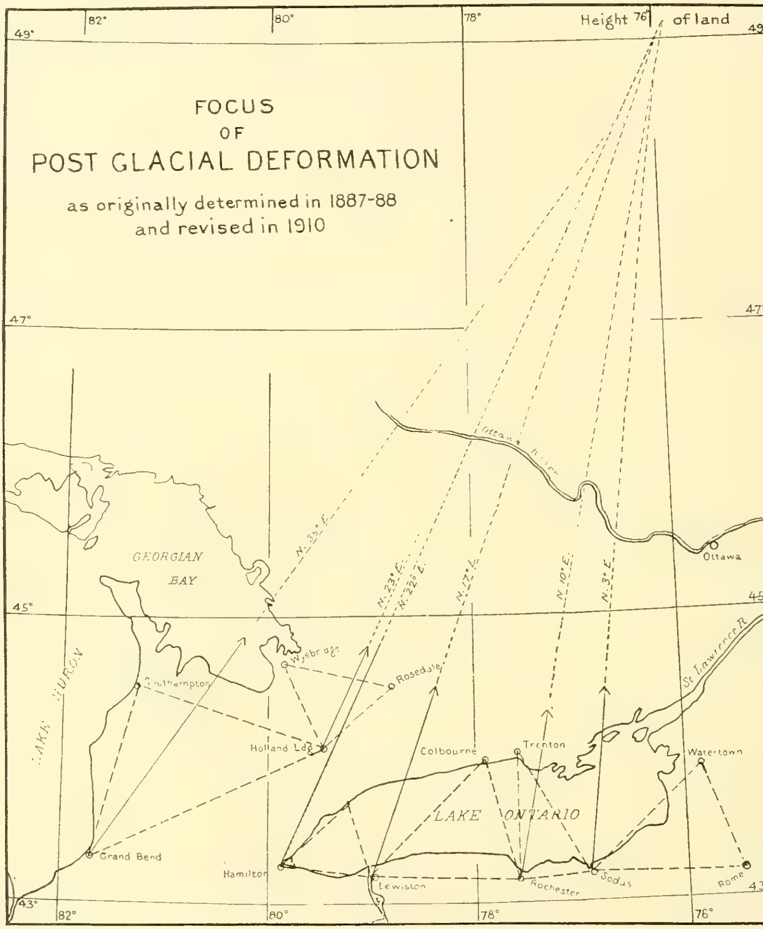

FIG. 1

and obtain the mean rate for each. These should cover the surveyed region, and be as nearly equilateral or right-angular as possible. Thus the following results have been obtained.

The mean rate of rise from the lowest points in the triangles and the direction, based upon the height of the Iroquois beach, cover the region of Lake Ontario.

Triangles between

Hamilton, Lewiston, and Scarboro,[1] 2 feet, N. 22° E.
Lewiston, Rochester, Colborne, Ont., 2.5 feet, N. 17° E.
Rochester, Sodus, Trenton, Ont., 3.6 feet, N. 10° E.
Sodus, Rome, east of Watertown, N.Y., 5.5 feet, N. 3° E.

These lines converge approximately in lat. N. 49° E., and long. 76° W. With the revised figures, the longitude is found to be the same, while the latitude is only 60 geographical miles north of the original determination, with the meridian of maximum uplift found to be just beyond the eastern end of Lake Ontario as originally computed.

Based upon the rise of the Algonquin beach east of Lake Huron, the mean rise in the triangles is found to be:

Between

Grand Bend, Southampton, and Rosedale, 1.3 feet per mile, N. 35° E.
Holland Landing, Wyebridge, and Rosedale, 3.4 feet per mile, N. 23° E.
Bradford, Owen Sound, Wyebridge, 3.1 feet, N. 27° E.

Combining the former of these triangles with those about Lake Ontario, the lines of rise from Grand Bend, and from Holland Landing, converge to the same point as those from Lake Ontario, but if the mean rate for the third triangle (which takes in a more western equivalent) be used the focus will be in about lat. 48° N.

Upham, Taylor, and Leverett have found the rate of rise in the region to the northwest to be of smaller amount, where Goldthwaite suggests that the rise also somewhat coincides with the height of land as found by me farther east in 1888, where the maximum amount is computed at some 250 miles north of Ottawa City, or a few miles to the west of this meridian.

The inferences to be drawn from these observations are: (1) that until a downward slope shall be found, we should conclude that the rise described continues to near the region indicated, beyond which the postglacial warping is downward; (2) that eastward of the 76th meridian, for any assumed latitude, the postglacial rise disappears and comes to be replaced by a downward slope. This is a question that has given the writer much solicitude, in an effort to determine the locus of downward warping in the

[1] At a point 12 miles east of Toronto. If, in place of this, the elevation at Carlton (5 miles west of Toronto station) be taken, the line of rise is found to be N. 27° E.

field. As the higher beaches have been found by all of us to indicate the greatest amount of warping, we should not expect to find a great amount in the altitudes of the Champlain marine deposits, but we see these recurring at so many points to about 500 feet above sea-level, that, upon examining their locations in the St. Lawrence Valley, it is noticeable that they occur along segments of the circle, roughly speaking, with the radii converging to the vicinity of the focus found; while in receding toward Gaspé, New Brunswick, and Nova Scotia the marine deposits rise only to lower and lower altitudes. These data are well known, so that an undue demand on the reader's patience need not be made by their repetition here. So also with regard to most of the elevations on the Iroquois and Algonquin beaches. Again, the eastern equivalent of the warping of the Iroquois, south of Lake Ontario, and in the Mohawk Valley, supports the hypothesis of declining postglacial warping in that direction, after passing the eastern end of Lake Ontario.

The question of the location of the line of maximum postglacial elevation radiating from the region mentioned raises several points in physical geography; one of these being the explanation of the cause of the rise, as due to the disappearance of the glaciers, for this locality was hardly the center of glacial dispersion. This idea, however, is here thrown out for others to consider.

Since these notes were written, the admirable paper of Professor Goldthwaite on the "Isobases of the Algonquin and Iroquois Beaches" has appeared. While the treatment of the postglacial warping by isobasic lines is scarcely other than a different mode from determining the mean rise in the various triangles, yet each has a significance of its own. The isobases indicate a regional rise toward the Laurentian axis. The triangles carried this rise to the "Height of Land" and show the locus of maximum rise north of the Great Lakes.

Note on the Accompanying Map

The triangles about Lake Ontario are based on the instrumental measurements of the Iroquois beach, at the places on the map; those east of Lake Huron, on the measurements of the Algonquin beach. Height, at Rome and Sodus after Fairchild, of Holland Landing and Rosedale (in place of my Kirtvill) after Goldthwaite. The other points are from my own surveys.

A GEOLOGICAL ROUTE THROUGH CENTRAL ASIA MINOR

FROM AFIUN KARA HISSAR VIA SIVRI HISSAR, ANGORA, SUNGURLU, AND THE MALYA TCHÖL TO CAESAREA

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New Brunswick, N.J.

The following paper is the summary of a series of notes taken in the summer of 1907, in connection with the Cornell Expedition to Asia Minor and the Assyro-Babylonian Orient. In a worked-over area like most of Europe and the United States, such a series of observations, probably somewhat inaccurate because of their hurried character, would add little to our knowledge. But in central Asia Minor the case is far different. Travel has been difficult and travelers are few. The men who have studied the geology of even a part of central Asia Minor could be numbered on one's fingers, and but one or two of them had the advantage of being trained geologists used to the work and to the country, and with the leisure to stop and examine.

For this reason it is that these notes represent new territory in practically their whole length. At certain points only did we cross (geologically) known territory.

The observations were taken from horseback, as had to be done under the conditions of travel. It was rarely possible to stop to investigate a place or to visit again one that had been passed. This must have resulted in some errors, especially as the caravan could not carry any great weight of specimens.

Frequently the rocks were fossiliferous, making their date certain, but unconformities were so frequent that it was not wholly safe to consider surrounding rocks as of the same date as the fossiliferous strata. Specimens were preserved wherever fossils were found (the majority were Eocene nummulites). These are deposited in the museum at Harvard and a study of them by

specialists would certainly result in a more accurate dating of many strata.

Because of the peculiar conditions the description will usually follow the itinerary of the party, which was as follows: Afiun Kara Hissar,[1] Phrygian Monuments, Aktash Köpri, Sivri Hissar, Gordium, Polatly, Hammam (Haimané), Giaour Kalesi, Angora (Enguri), Assi Yuzgad, Yakshy Khan, Izz-ed-Din, Sungurlu, Boghaz Köi—with a sidetrip to Eyük—Yuzgad, Medjidié, across the Malya Tchöl to Bash; Hadji Bektash, Kara Burun, Avanos, Inje Su, and Caesarea (Kaisari). At this point the author was obliged to leave the party and hurry back to Constantinople. A few notes were taken from the train north of Afiun Kara Hissar which have been used to help out the map of that section.

Distances are reckoned roughly in hours (at the rate of a walking horse, three miles an hour), as that is the usual unit of measurement in the country.

The principal geologist of Asia Minor was Tchihatcheff,[2] and his map remains the only one of much of the country. His work is now fifty years old and an experienced modern student would doubtless modify much of it. Still to the present time the man who has his books at his elbow will not miss very much of what is known of the geology of the eastern two-thirds of the territory.

Yuzgad, and on an even grander scale, Caesarea, are in the center of regions which should prove exceedingly interesting. The complex resulting from several periods of igneous action makes a fascinating puzzle to disentangle. At these points I can add almost nothing to Tchihatcheff's account, but can fully verify the existence of the confusion he reports.

Because of the impossibility of determining the date of most

[1] I have not been entirely consistent in my transliteration of native names of places, etc. There is no established method, and two books on the country will hardly agree in their methods. *I* and *y* (vowel), in particular, represent different sounds in Turkish, but they are not sharply defined and I should perhaps have used *y* more freely than I have. The distinction between *q* and *k* also generally represents a mere difference in Turkish spelling. *Q* might perhaps have been used more freely, following Arabic precedent.

[2] I follow the spelling of Tchihatcheff's name as it appears on the title-page of his large work—in French. It is spelled differently in the German reports of his travels.

of the rocks, they are classified on the maps rather from superficial characters. I have specially indicated the points where fossils have been found. The rocks may be grouped as igneous (of various sorts), metamorphic (largely Paleozoic where their relationships are known), obliquely stratified (Mesozoic and Eocene, especially the latter), and horizontally bedded sedimentaries (Miocene and later as a rule). Thorough tracing-out of the relationships of strata and thorough collecting of the fossils can alone give a much more accurate knowledge of the dates of the various deposits of Asia Minor.

In connection with the regular archaeological report of the expedition I expect to publish this matter in a less technical way and with reference rather to its interrelation with the various past peoples of Asia Minor and their culture.

I wish to express my indebtedness to the members of the expedition in many ways, and especially to Jesse E. Wrench, who did most of the topographic work; also to Professor J. B. Woodworth, under whose direction and advice this report was prepared, and to the other authorities of Harvard University who have helped me in the matter of books, instruments, etc.

MOUNTAINOUS PHRYGIA

Comparatively few notes were taken in this district, and no specimens were collected. The substratum of the country is metamorphic, appearing as schists along the railroad cut between Ihsanié and Düver (Deuyer), at the entrance to the mountainous section southwest of Ayaz In, and in smaller bands east of Yazili Kaya. There were also three outcrops in the Sakaria plain, one a considerable band at the eastern end of the Yazili Kaya limestones, and the others east and west of Aktash Köpri, as shown on the map. Quite as frequently the metamorphic rocks were limestones. This was the case along the railroad, north of the mapped area for a considerable distance, and also in a large area all about Yazili Kaya.

Overlying the metamorphic rocks are everywhere igneous rocks, Neocene in date. These lie in horizontal beds, lavas, or tuffs, and are sometimes so rotted as to be indeterminable. Of the

same period also are several local deposits of sandstone and conglomerate. These are cut by the railroad near Hammam and elsewhere; they form the basis of many of the sculptured rocks of the country. More frankly volcanic are the white tuffs of Ayaz In, and the lava mesas which make a dominant feature of the landscape east of the railroad, and all about Yazili Kaya.

The lacustrine gravels of the Sakaria Valley approach quite close to Yazili Kaya on the east and mark the northeastern boundary of Mountainous Phrygia.

As reported by Tchihatcheff and Hamilton the region south of the author's route is of the same character, but the dominance of igneous rocks becomes less. The conspicuous volcanic necks of Afiun Kara Hissar are well described by Tchihatcheff and others.

THE SIVRI HISSAR RANGE

Passing over the lacustrine plains of the Sakaria River for the present, we reach the next point of interest in the Sivri Hissar Mountains, conspicuous among them Kodja Bel. At this place the stratified rocks would seem to belong to the same group as those in Phrygia, but the core of the range is a granite (a syenite in the popular sense of the word, as it is a fine-grained granite with little or no mica). East of Bala Hissar there is an area of limestone on the very top of the range, surrounded on both sides with the syenite, apparently lifted up on top of it. Near the city (Sivri Hissar) there is a complex of metamorphic rocks (schists and gneiss), through which the road passes on the east side of the mountains. Kodja Bel, a conspicuous peak southeast of the city, and the Kaimas peak to the northwest, seem to be similar.

Tchihatcheff has reported on the northwestern part of the range; conditions are essentially the same, an alternation of syenite (granite) with various metamorphics.

GORDIUM AND POLATLY

The neighborhood of Polatly, unlike the preceding localities, has fossiliferous rocks, making it possible to fix this district as *Eocene*. Nummulites are the dominant feature, as elsewhere in Asia Minor eocenes.

To the west of the Sakaria no Eocene rocks were found *in situ*, but the cairns built by the shepherds are of fossiliferous limestone.

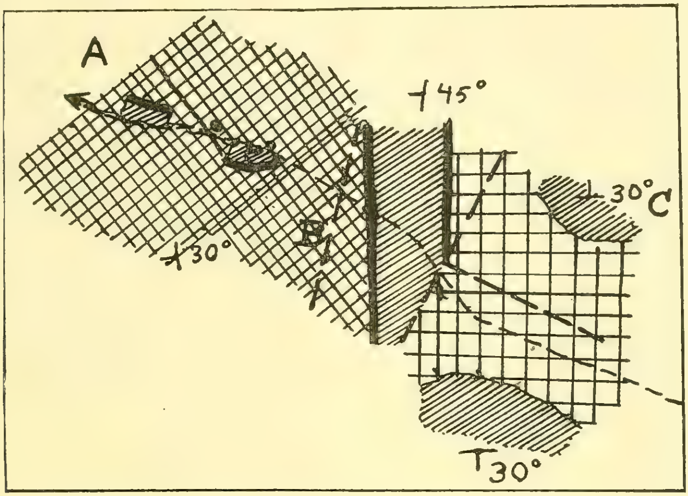


FIG. 1.—Sketch of the hills southeast of Gordium, interpreted as a laccolith. The stratified shales are indicated with fine oblique hatching; the lower trap is coarsely, and the upper trap finely, cross-hatched. The baked layer of the shales is shown solid black. Possible faults are indicated.

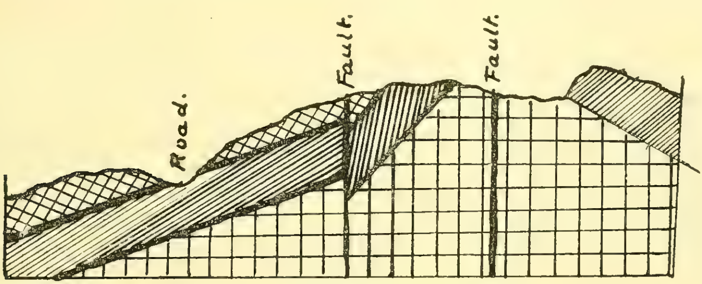


FIG. 2.—Cross-section through ABC. The symbols are the same as in the preceding figure.

Probably outcrops of the rock occur. On the east side of the river the lacustrine plain is quite narrow, and is replaced by hilly country. This is composed, to the south of Polatly, largely of Eocene limestones, but farther north of light-colored (yellow or

greenish) shales, which have the appearance of hardly consolidated clays.

There were also many outcrops of a dense igneous rock, necks southwest and east of Polatly, and sheets nearer to the village and to the northwest. To the northwest, as the plan shows, the situation becomes quite complex; in the plan the strata are interpreted as representing a laccolith, with overlying sedimentary rocks and flows, sloping away in at least three directions from its uncovered core. The eastern part was, unfortunately, passed over in the night, so that I cannot say whether the conditions were the same on that side or not. Overlying the sedimentary rocks was a sheet of lava. This had baked the clay red for the thickness of about a foot, making a very conspicuous layer. The red color was quite extensive toward the north, east of Gordium, so probably the trap sheet had once been much larger, but has been eroded off, leaving only the baked brick layer as a memento. At present, of course, these deposits can only be marked as "probably Eocene."

Hamilton reports similar mixtures of sedimentary and trap rocks north of Polatly, in the neighborhood of "Begesch" (Beydjez or Beikos?).

HAIMANÉ

Separated, at least in the line of our route, by a region of recent deposits, from the Polatly limestones and shales, there lies to the east the strikingly arranged Haimané district. In the immediate vicinity of Hammam no fossils have been found, though the rocks (shales) look promising enough. At Kaya Bashy there were plenty of shells in a limy conglomerate, apparently largely Anomias, but they were so much injured in transport that one can hardly determine whether the rocks belong with the eocenes of Polatly, or with the Jura and Lias which other authors have reported to the west of Angora. While Tchihatcheff, who has passed through the district at right angles to our route, considers them as probably Jurassic, I should incline rather to the other conclusion, especially as some of the Polatly nummulites were in quite similar-looking rocks.

At any rate, they are sedimentary deposits, obliquely banded,

very brilliantly colored in red and yellow, and rarely obscured by plant cover, so that their bedding can be traced for long distances. No unconformities were noticed, but the point of transition between the shales immediately about Hammam and the calcareous conglomerates and sandstones to the north was not seen. As reported by Tchihatcheff these deposits must be very extensive to the north of our route; in fact they and others similar dominate the formations of central Asia Minor.

A gorge about an hour north of Hammam, near the village of Arif, passes through a mass of much denser limestone, which seemed to be conformable to the other deposits, but was very different in appearance. It is indicated by heavier hatching on the large map.

Giaour Kalesi is close to the boundary between the series of sandstones just described and one of the great plains that make the type-landscape of central Anatolia. The boundary runs northeast and southwest, and was followed most of the way from Hammam Merkes to the Hohan Göl. The castle itself, however, is on a pinnacle of very different rock, more similar to those which wall the gorge at Arif and also to those at Angora and Assi Yuzgad. It may then be of the same period as the surrounding rock, or with the Angora series, much older. There was no noticeable continuation of it through the surrounding rolling country. All the apparently earlier walls of the castle were built of it. The stones were small and yet show no great signs of weathering, in marked contrast to the condition of Boghaz Köi, also built of its local marble during the same period of history. Less than an hour east of Giaour Kalesi is the village of Oyaja, built about the base of two trap necks, like a miniature Angora. These, or other similar outcrops, furnished the material for the later heaviest walls of Giaour Kalesi.

Looking off from the top of Giaour Kalesi the hills seemed spotted with deep green, the characteristic mark a little farther east of the serpentines, and here doubtless due to the same cause. The spots seemed to have no regular arrangement and perhaps marked small volcanic necks, which, being soft, did not project above the general level.

THE ANGORA DISTRICT

In the neighborhood of Angora I first came across the confused mass of rocks that seems to be typical of the igneous areas of Asia Minor. We stopped some time at Angora, and a day at Ortaköi, near by, giving rather more opportunity than usual to study the conditions. The series that leaves the strongest impression with one is a group of schists, extending roughly northeast and southwest, alternating between dark schists with hornblende or mica, sometimes very dense, and a very friable, whitish type, which seemed to have talc or sericite for its foundation (a snap-judgment, as there was of course no opportunity to go back). Neither of these types had the superficial appearance of stratified rock, but the relation of the two schists to each other and to the limestone of Elma Dagh convinces me that they were originally sedimentary. Tchihatcheff calls the whole system serpentine, and considers it igneous. They were apparently interrupted by a lava flow from Angora, southeast of the city where Tchihatcheff crossed the Elma Dagh, but the clay-slates, "Thonschiefer," on the road south from Angora, would seem to belong to the same bed; at least they have the same relation to the limestone.

I crossed the entire width of the schists, going a few rods north, and three miles south, from Ortaköi. South of Angora the Thonschiefer were of about the same width.

The marble was traversed in two places, and was also noted by Tchihatcheff about half-way between these two, giving a good idea of it. It seems to form the whole crest of the Elma Dagh and may extend quite a little farther at each end. Hamilton and Tchihatcheff's notes would however seem to indicate that it is limited by Jurassic sandstones to the southwest, and apparently to the northeast also before reaching the Kyzyl Yrmak. Might the coalbeds reported near Kalejik, on the Kyzyl Yrmak, belong to the same system? To the north the schists were very soon cut off by igneous rocks of various kinds, but Hamilton reports both schists and limestones again north of them for some twenty miles northeast from Angora.

The most typical of the igneous rocks are the necks which rise in Angora itself. These are of a reddish or purple trachytic

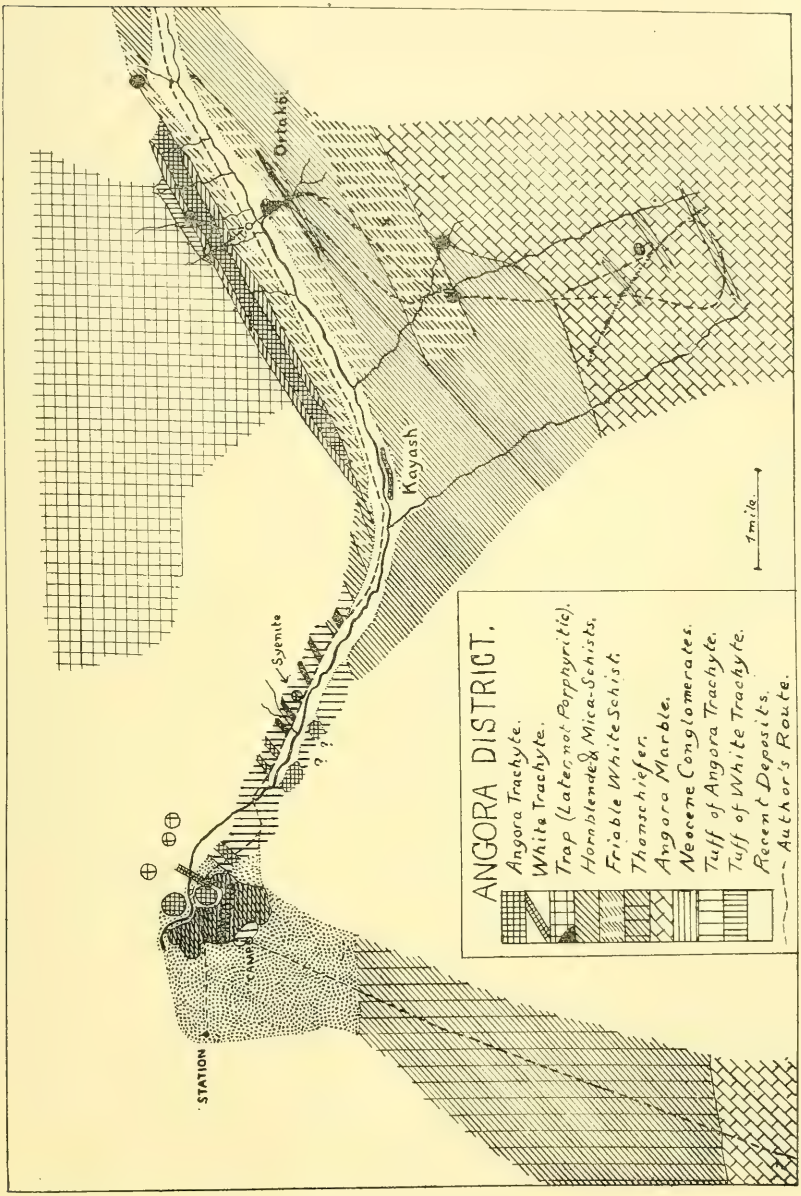

ANGORA DISTRICT.
Angora Trachyte.
White Trachyte.
Trap (Later, not Porphyritic).
Hornblende & Mica-Schists.
Friable White Schist.
Thonschiefer.
Angora Marble.
Neocene Conglomerates.
Tuff of Angora Trachyte.
Tuff of White Trachyte.
Recent Deposits.
Author's Route.
1 mile.
Ortaköi
Kayash
Syenite
CAMPS
STATION

Fig. 3

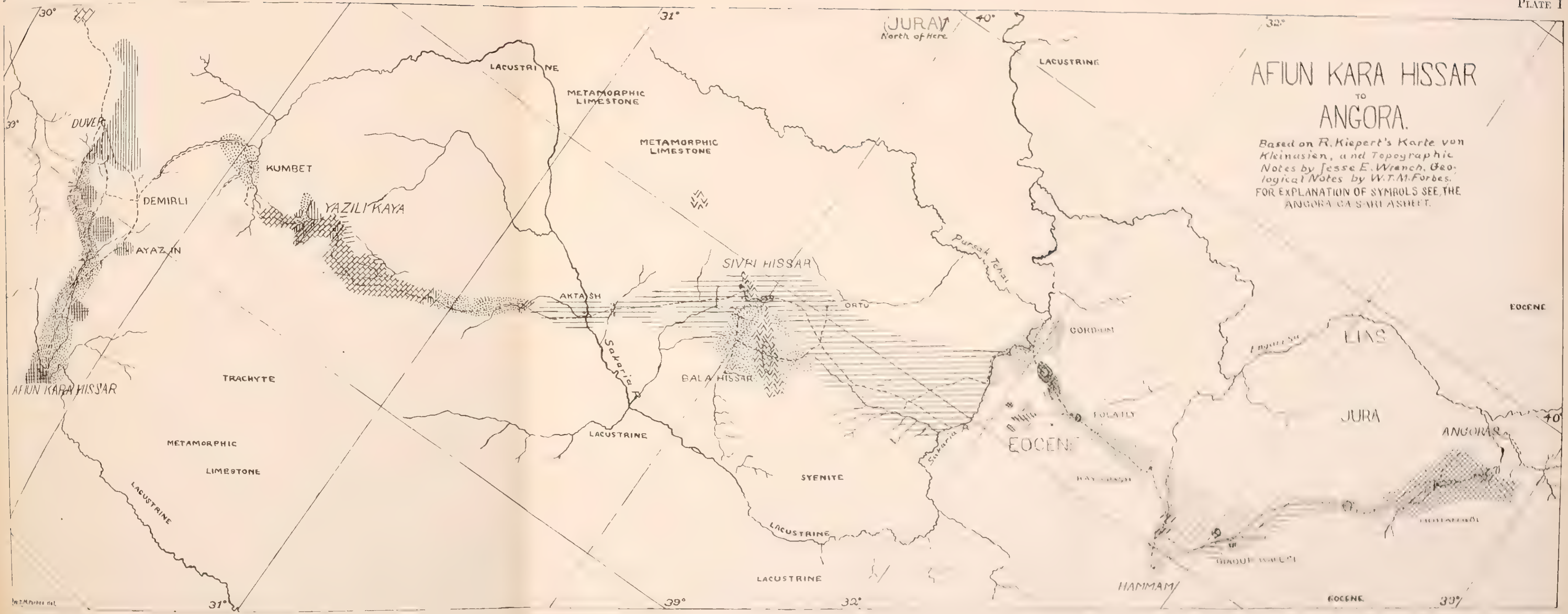
porphyry.[1] The tuff which covers large areas east of the city, and makes the hill west of it, is made of the same volcanic rock. North of Ortaköi there is a long outcrop of the same type of rock, apparently here a lava flow, interbedded between two layers of late conglomerates, which in their turn have been made up of the schists, etc., of the region, and also of a fine-grained sandstone evidently not very old. Over the upper bed is a layer of white tuff, which one would naturally associate with the trachytes at Angora, and over this again a flow of very dark trap of indefinite extent. This trap would seem to make all the mountains to the north, at least for some distance. There are also dykes of it cutting all the earlier beds, and necks of it north and northeast of Ortaköi. There is a small neck of the Angora trachyte also penetrating the limestone three miles south of Ortaköi.

To sum up, there seem to have been the following periods of deposit: (1) the system of limestones and schists which were probably metamorphosed and eroded before the next period; (2) the sandstone which formed an element of the conglomerates, and so must have had time to become consolidated before the date of the eruptions; (3) the eruptions of Angora trachyte, forming also the white, and porphyry tuffs (during lulls in this the conglomerates north of Ortaköi were deposited by the precursor of the Enguri Su); (4) the period of the dark traps. Since the last there has been time for the whole lansdcape to be eroded down to its roots, leaving even the latest volcanic rocks as necks, and flows which have been tilted to decided angles.

Almost a continuation of the Angora complex is the district about Kylyjlar. Just north of Assi Yuzgad there is a volcanic mass, apparently a sheet extending northward. Soon after reaching the hilltop the marbles about Assi Yuzgad, which have dominated since the last watershed west of the town, are in their turn replaced by an area of dense dark volcanic rock, mostly altered into serpentine, which extends, with various admixtures, almost

[1] Bukowski has studied the igneous rocks of this district at some length. He finds the dominant rocks to be a variety of andesite, with quite a number of other igneous types, however. So probably the so-called trachyte and trap of the older geologists of Asia Minor should often be interpreted rather as andesite. He traces the extent of this igneous area to the north. See the Bibliography.


AFIUN KARA HISSAR
TO
ANGORA.
Based on R. Kiepert's Karte von Kleinasien, and Topographic Notes by Jesse E. Wrench. Geological Notes by W. T. M. Forbes.
FOR EXPLANATION OF SYMBOLS SEE THE ANGORA-CÆSAREA SHEET.
32°
33°
40°
USTRINE
EOCENE
GORDIUM
Enguri Su
LIAS
JURA
POLATLY
NE
ANGORA
KAYA BASH
MOHAN GÖL
GIAOUR KALESI.
HAMMAM
EOCENE


AFIUN KARA HISSAR
TO
ANGORA.
Based on R. Kiepert's Karte von Kleinasien, and Topographic Notes by Jesse E. Wrench. Geological Notes by W.T.M. Forbes.
FOR EXPLANATION OF SYMBOLS SEE THE
(JURA)
North of Here
LACUSTRINE
METAMORPHIC LIMESTONE
DUVER
KUMBET
DEMIRLI
YAZILI KAYA
AYAZ IN
AKTASH
SIVRI HISSAR
ORTU
Pursak Tchai
Sakaria R.
BALA HISSAR
TRACHYTE
AFIUN KARA HISSAR
SYENITE
EOCENE
JURA
LIAS
ANGORA
HAMMAM
30°
31°
32°
33°
39°
40°

to the Kyzyl Yrmak. For the first couple of miles it is interrupted by several reappearances of the marble. Two of the hills south, also, are crowned by later horizontal beds. The dominance of the serpentines gives the whole country as far as one can see a deep green tint, varying in spots to pale green and to liver-red. After crossing a broad alluvial plain without outcrops, and then a narrow ridge of volcanic rock similar to the deposits to the west, we reach the immediate vicinity of Kylyjlar.

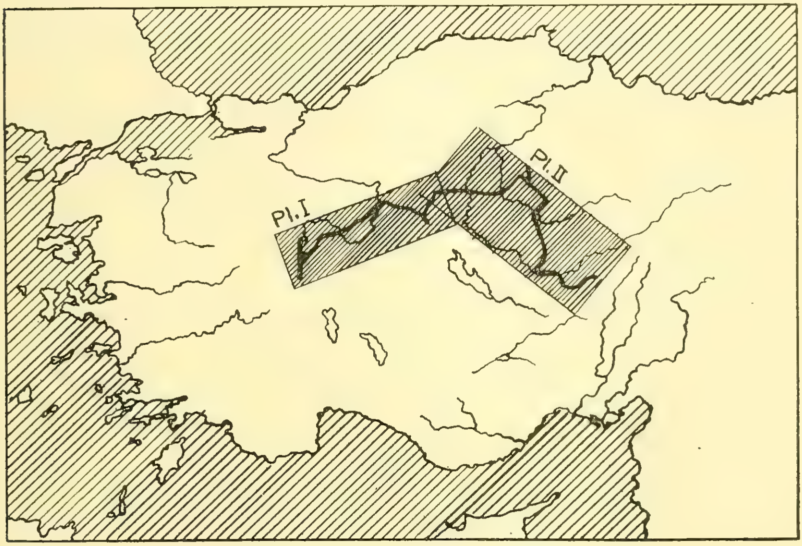


FIG. 4.—Index map of Asia Minor.

On the east slope of the last ridge west of Kylyjlar, there is a small outcrop of schist, dipping steeply to the northwest, and similar to that east of Angora. Underlying it is a small patch of syenite, not indicated on the map, and east of that again a flat-topped hill that dominates the whole valley. This hill seems to be formed of the serpentines, but is capped with a layer of the gray and white Angora limestone, apparently originally continuous with the beds east of the valley. East of Kylyjlar the dominant rock is still the same serpentine, but with the denser type less common, and more mixed than before with the greenish white tuffs (?). For a mile immediately east of the town, however, it

is clearly a tuff with large pieces of the dense volcanic rock as a foundation.

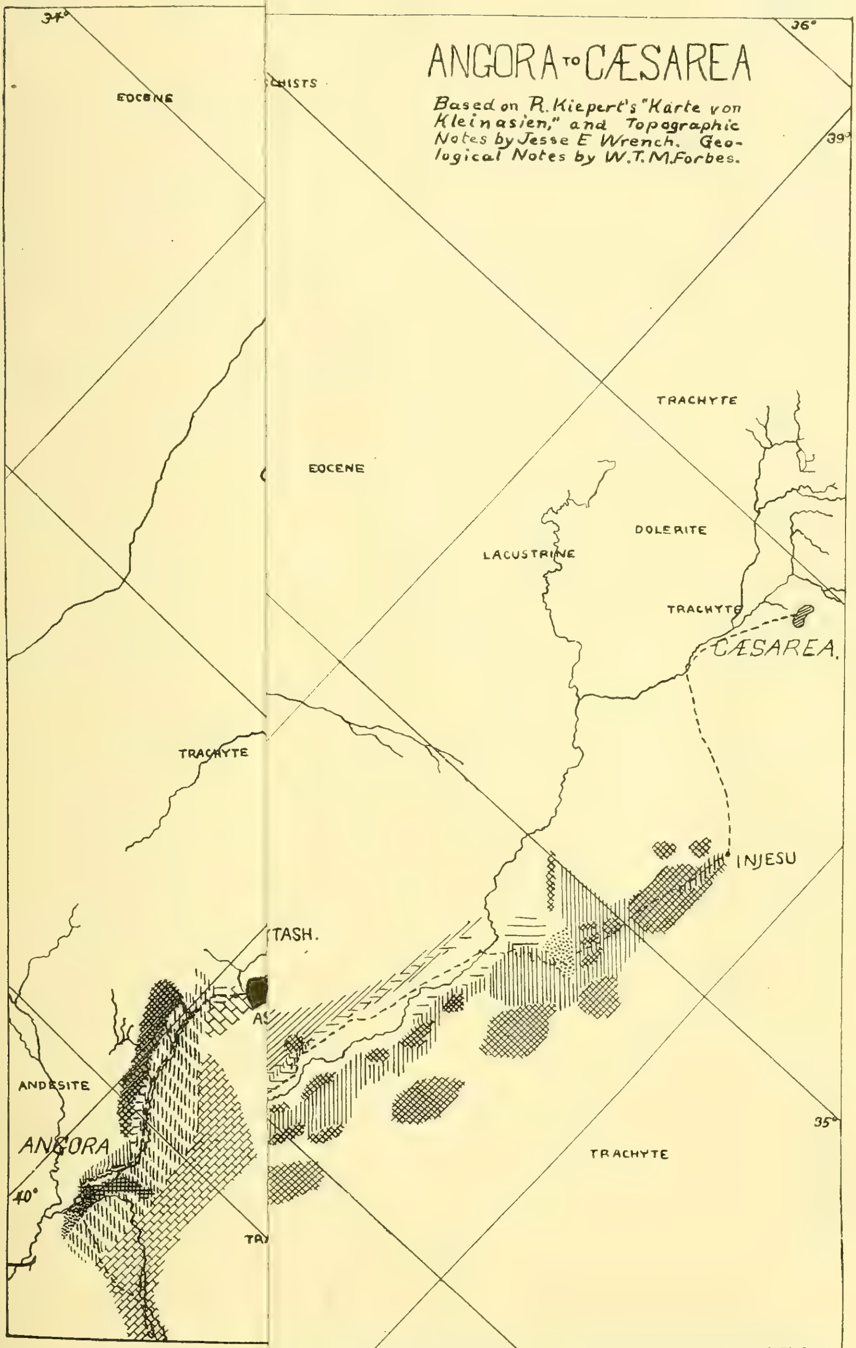
Interbedded with this tuff there comes in quick succession a series all dipping northeast: in order going eastward, conglomerate, Angora limestone, tuff, limestone, tuff again. There is also a very conspicuous line of the pale-green rock running south behind Kylyjlar, parallel to the valley. I did not find its contact with the stratified rocks, possibly a dyke of some kind. The marble appears in several other places between this district and the Kyzyl Yrmak, and also (but here the white crystalline type we found about Assi Yuzgad) in a prominent hill just across the Kyzyl Yrmak.

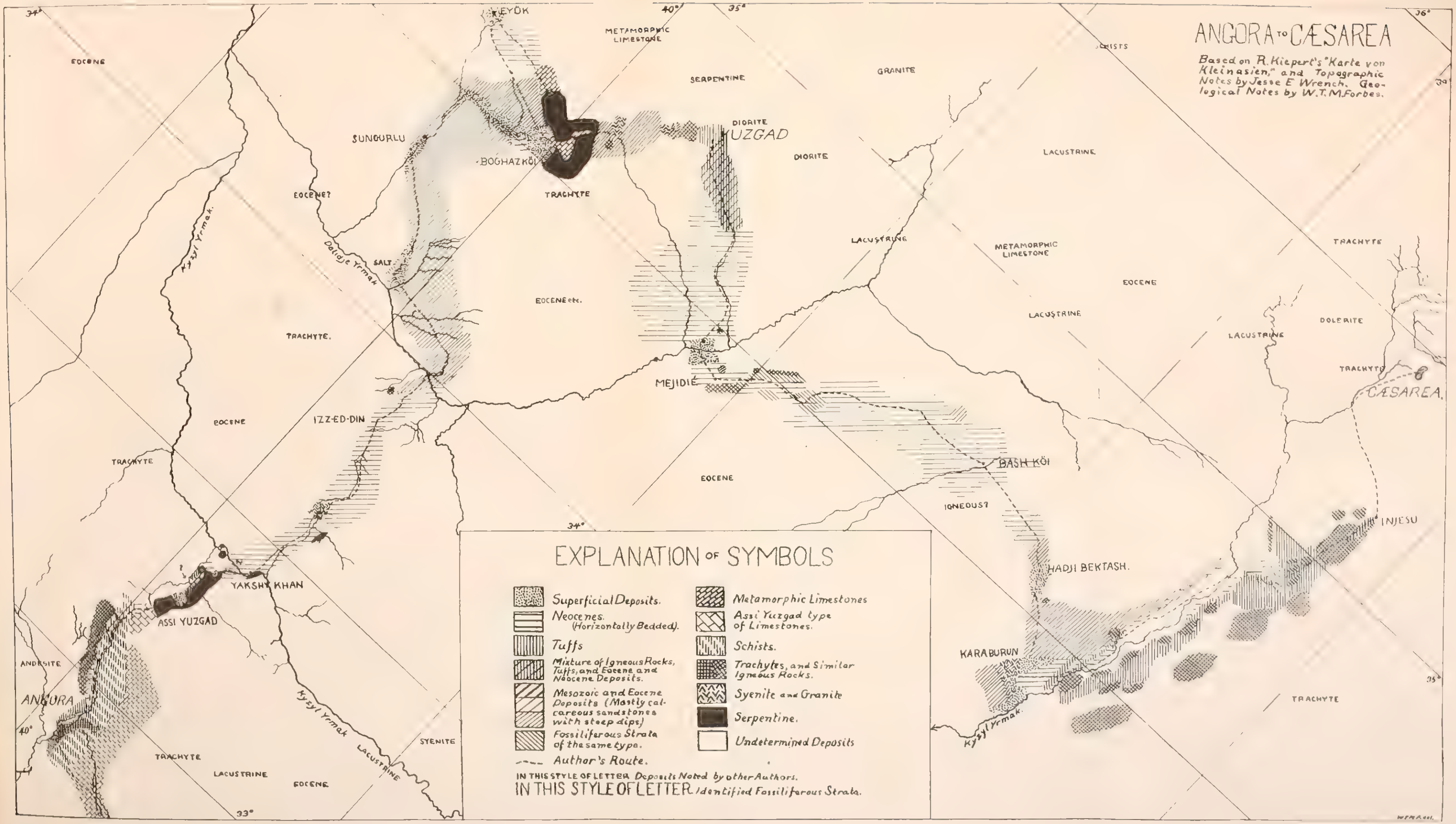
Two miles east of Kylyjlar the serpentines east of the path are replaced by syenite, but they continue south of the syenite, and underlie the Neocene rocks for a distance farther. On leaving the syenites, now only a long mile from the river, we ourselves strike into the Neocene deposits that fill the bed of the river and extend indefinitely eastward. The neocenes are an alternation of conglomerate, sandstone, and a fine-grained rock like pale-brown sugar (perhaps the "saccharine limestone" of Tchihatcheff). The latter is well exposed immediately around Yakshy Khan and seems to be the top layer of the series.

THE SUNGURLU SERIES

The section between the Kyzyl Yrmak and the Delidjé Yrmak is dominated by Eocene deposits. However, here and there igneous masses were seen, and they were probably numerous off of our route. Apparently serpentines form considerable outcrops south of Yakshy Khan, along the west bank of the Kyzyl Yrmak, and about a third way to Izz-ed-Din it again becomes probable that the distant rocks to the south are serpentines. An hour northeast of this last deposit there is a very conspicuous outcrop of syenite, cut from east to west by a crooked gorge which serves as a road. Immediately north of Yaghly there is evidently another igneous outcrop abruptly cut off to the south by a small brook, in a way that suggests the possibility of a fault running northwest and southeast.

East of this line, almost as far as Eyük, and from there south


ANGORA TO CÆSAREA
Based on R. Kiepert's "Karte von Kleinasien," and Topographic Notes by Jesse E Wrench. Geological Notes by W.T.M.Forbes.
34°
36°
39°
35°
40°
EOCENE
EOCENE
TRACHYTE
DOLERITE
LACUSTRINE
TRACHYTE
CÆSAREA.
TRACHYTE
INJESU
TASH.
ANDESITE
ANGORA
TRACHYTE
W.T.M.F. del.


ANGORA TO CÆSAREA
Based on R. Kiepert's "Karte von Kleinasien," and Topographic Notes by Jesse E. Wrench. Geological Notes by W. T. M. Forbes.
EXPLANATION OF SYMBOLS
Superficial Deposits.
Neocenes. (Horizontally Bedded).
Tuffs
Mixture of Igneous Rocks, Tuffs, and Eocene and Neocene Deposits.
Mesozoic and Eocene Deposits (Mostly calcareous sandstones with steep dips)
Fossiliferous Strata of the same type.
Author's Route.
Metamorphic Limestones
Assi Yuzgad type of Limestones.
Schists.
Trachytes, and Similar Igneous Rocks.
Syenite and Granite
Serpentine.
Undetermined Deposits
IN THIS STYLE OF LETTER Deposits Noted by other Authors.
IN THIS STYLE OF LETTER Identified Fossiliferous Strata.
EYÖK
SUNGURLU
BOGHAZKÖI
YUZGAD
MEJIDIE
IZZ-ED-DIN
YAKSHY KHAN
ASSI YUZGAD
ANGORA
BASH KÖI
HADJI BEKTASH
KARABURUN
INJESU
CÆSAREA
Kyzyl Yrmak
Delidje Yrmak
EOCENE
TRACHYTE
METAMORPHIC LIMESTONE
SERPENTINE
GRANITE
DIORITE
LACUSTRINE
SALT
ANDESITE
SYENITE
DOLERITE
IGNEOUS?
SCHISTS

to Yuzgad, rocks of Eocene facies were constantly in sight, the immediate vicinity of Boghaz Köi making the only serious interruption. In the immediate vicinity of Aktché Köyün our route took us out of this Eocene area into the lacustrine plain which so often accompanies the larger rivers of Anatolia.

The rocks of Eocene facies dip at various angles, and do not seem to be entirely conformable. However, as in unquestionably conformable series in that vicinity the dips and strikes often change very abruptly, I should not dare to say that more than one period is represented. One may take, for instance, the case sketched here. This is a frontal view of a bluff, past which the

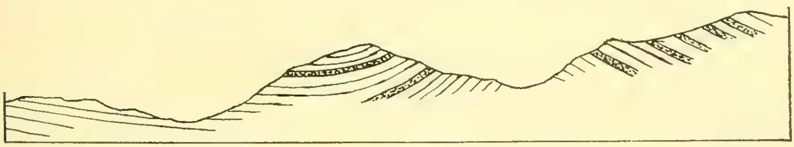


Fig. 5.—Frontal view of a bluff a short distance east of Alembeyli, showing very rapid change in dip of the strata. The stippled layers represent gypsum; the rest is sandstone. The road passes through the right-hand depression. (Somewhat diagrammatic.)

road ran (through the central gap, in fact). The entire part of the ridge shown in the figure was but a few rods long, and as one can see, the dip of the strata has changed considerably. Actually aside from this anticlinal structure the whole series dipped away moderately. At this particular point, near Alembeyli, there was some tendency for the dips to be moderate and easterly. Southwest of Aktché Köyün the dips of the nearer strata were about the same, but some strata were seen dipping at angles of over 45°. As already mentioned the two sets *appeared* unconformable but this may have been because of inability to see the intermediate rocks.

At Sungurlu, at the east end of the village, there is a thin bed of plant remains, but they proved too fragile for transport.

BOGHAZ KÖI

The dominant rock at Boghaz Köi is a marble breccia, with a bright red cementing material, making a striking pattern. Occasionally the marble is more massive, and then may appear either

like the Angora or the Assi Yuzgad types, showing that the latter two can well be of the same date.

Mixed all through with these marbles is a serpentine, in which, wherever the outcrops are clear, the marble appears to be floating

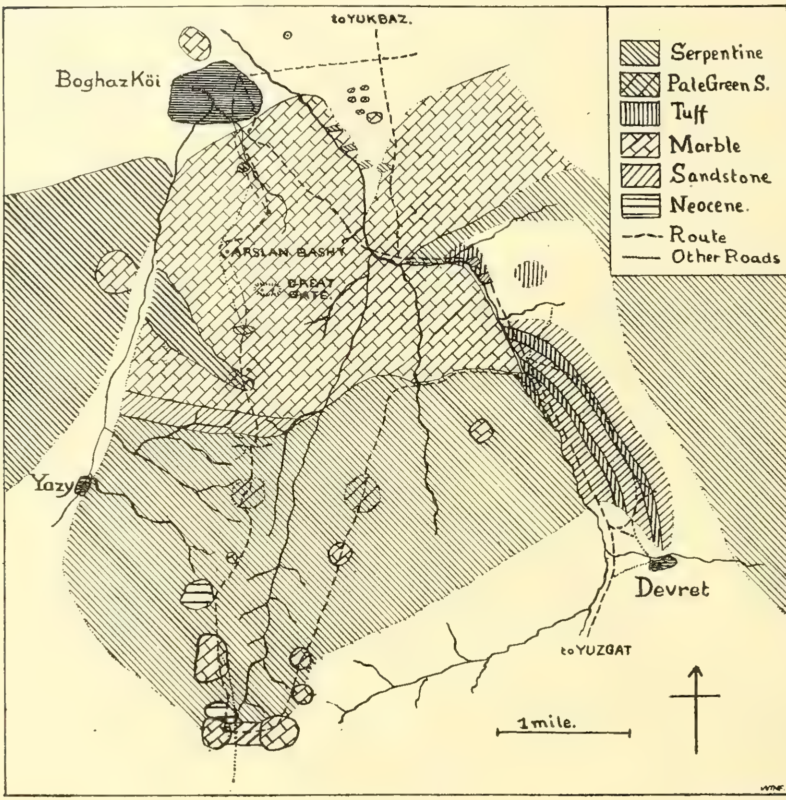


FIG. 6

in large blocks. The serpentine is less in evidence immediately under the ruins at Boghaz Köi, but even there the excavations have exposed it enough to suggest that the arrangement is the same.

At the point where the dominant limestones give way to serpentines, as one goes south from the village and the ruins, there is an east-and-west bed of a dense siliceous rock that also appears

a second time farther south, interbedded with sandstones. In both cases the dip is northeast.

Farther east and up the main valley as far north as Devret the rocks and their arrangement are different. Here there are two bands of a dark tuff, with fragments of vesicular trap, imbedded in sandstone, and the whole dipping to the east. Where we went,

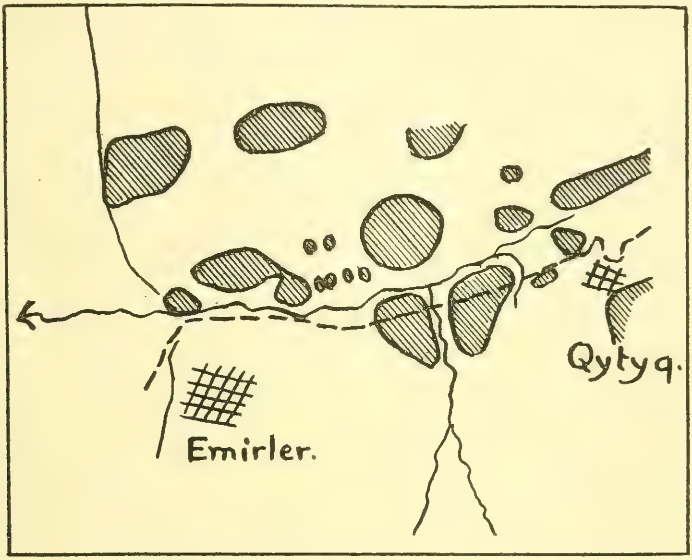


FIG. 7.—Sketch of a small area near Emirler, just north of Boghaz Köi, showing the relation between limestone and serpentine usual in that district. The hatched areas are limestone; the remainder is probably mostly or entirely serpentine, but largely covered up.

as shown on the map, it seems to disappear within a short distance under the serpentines. But it probably extends farther to the southeast and east, through the area left white on the map.

North-northeast of Boghaz Köi, the mixture of serpentine and marble continues half-way to Eyük, the serpentine dominating for the southern half and disappearing in the northern half. About at the point where the serpentine ceases to appear in any quantity there are several outcrops of denser igneous rocks. The space immediately south of Eyük is occupied by fine-grained Neocene limestones, containing plant remains in poor condition. A little

farther west, and more directly north of Boghaz Köi, there is no sign of the limestone or serpentine, but the Eocene (?) rocks which extend west to Yaghly take their place.

THE YUZGAD COMPLEX

Five or six miles south of Boghaz Köi the serpentines and limestones again make way for the rocks of Eocene facies, but now they are much interrupted by igneous rocks in great variety. Our road, the new chaussée, ran at first southeast, over the divide. Then we entered the valley of a large stream which flows off to the southwest and is followed by the old chaussée. We went upstream (to the east) for a couple of miles along one of its tributaries, after coming down from the divide along another; and then we turned abruptly southeast to cross the very top of Kabak Tepé, the mountain just north of Yuzgad, by a very complex system of zigzags. From the height of land till we left the main valley to climb Kabak Tepé, and actually till we were fairly up on the slopes of Kabak Tepé, the supposed eocenes make up the mass of the rock. Southwest of the road about a mile south of the divide there could be seen a flat mesa which has been used for "cliff-dwellings." It is probably a tuff or soft trap like the beds so used elsewhere, and made a distinctly incongruous note among the other rocks of the district. In any case it is Neocene in date, and unconformable on the local bedrock. Northeast of the road in the same neighborhood there are several appearances of granite (probably more nearly of the date of the bedrock). At the point of forking of the old and new chaussées, where the road ceases to go south down one tributary and turns east up the other, there are a couple of trap dykes, both small, but perhaps outliers from more extensive intrusions to the north.

A couple of miles south of the valley of the tributary running from east to west the supposed eocenes either disappear or else change their character entirely under the influence of the many igneous rocks, which now become dominant. Of this district one can only say that it is a practically inextricable tangle. It is composed, among other rocks, of granites, dark traps, schists, fragments of Eocene beds (some containing fossils according to Tchi-

hatcheff), tuffs, and Neocene sandstones and conglomerates. Immediately about the town there are several outcrops of tuff.

Hamilton and Tchihatcheff report the same types as making the entire region west to near the Delidjé Yrmak, and northeast for an equal distance. To the southwest, however, after about ten miles they gradually give place to neocenes, which extend in the main to Hadji Bektash. Tchihatcheff discusses this complex with the dolerites.

Getchi Kalesi, the mountain to the east of Medjidié, in the northern part of the Malya Tchöl, is only the culminating point in a limestone range, cored with trap, which extends from west of Medjidié southeast for a dozen miles. The limestones at several points contain Eoçene nummulites in quantity. At the point where the road traverses this series, south of Medjidié, the eocenes are not conspicuous, and the traps are locally interrupted, but behind the city, the traps stand up in a series of prominent and ragged hills. Even here I have a feeling that the igneous dyke is not entirely continuous. A little farther south, and on the other side of the path, the igneous rocks appear again in a couple of amorphous masses (as seen from a distance), the eocenes remaining inconspicuous, but Getchi Kalesi itself is of a somewhat different structure. The dyke here seems to be fairly continuous, and in general makes the crest of the ridge. Leaning against the west side of this is a long series of Eocene limestones, etc., all with dips of about 60° to the north. Apparently on the east side of the dyke the same facing occurs, and the very highest point of all is formed by one of these strata which is continuous across the top of the dyke. This very topmost point furnished one of my nummulite specimens, through the kindness of Mr. Wrench.

A little farther south the village of Mahmatly is situated in a very striking gorge, which marks the boundary between a lower and a higher level of the Malya Tchöl. On the steep sides of this gorge, as well as the escarpments that lead up to its mouth, the neocenes are interrupted, laying bare the substratum of the Tchöl, which is evidently of the same system as Getchi Kalesi mountain. Half a day's journey farther south there is a long hill a moderate distance west of the road, which again shows the

steeply dipping strata of the Eocene series. At one place *Nummulites lævigata* (Lutétien period of the Eocene) was picked up, but not *in situ*.

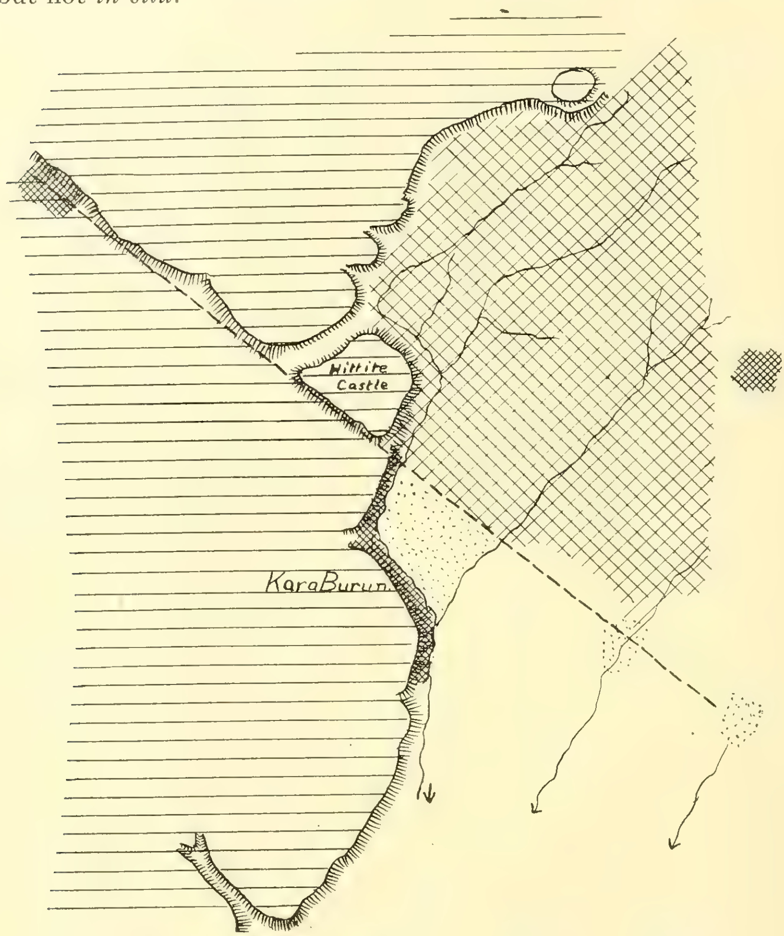


Fig. 8.—Kara Burun and immediate vicinity. The trap is indicated by horizontal lines, the granite by coarse cross-hatching. Gardens have been shown in stipple, indicating the position of springs.

There are also some smaller igneous outcrops in the neighborhood of Medjidié, which do not seem to belong to the Getchi Kalesi range, in particular a neck of very coarse porphyry some five miles northeast of that town and on the other side of the river.

The district between the Malya Tchöl and the Kyzyl Yrmak valley to the south is again apparently eocene in date, resembling closely in appearance the Haimané and the vicinity of Sungurlu. The very top of the divide south of Hadji Bektash showed no outcrops, but the pebbles brought down and the appearance of the distant hills would imply that it also had a volcanic core. It is a very much more insignificant ridge than Kiepert's map would suggest.

KARA BURUN

The village of Kara Burun is located on the east slope of a mesa capped with a sheet of hard black trap. This sheet disappears abruptly at the north end of the village against a steep bluff of much-rotted granite, which in its turn is capped with a second sheet of trap exactly similar to the first, but on a higher level. The lower level trap, like the upper, seems underlaid with granite.

East of the upper level, the granite is laid bare in several places, but east of the lower level there are no near outcrops. On the south boundary of the granite outcrop there is a line of springs marked by gardens and villages, of which the first is Kara Burun itself. The whole, with the line between the upper and the lower Kara Burun traps and the southern boundary of the Eocene deposits farther to the east, forms a line nearly parallel to the Kyzyl Yrmak river which I have interpreted as possibly a fault.

East of Kara Burun the Kyzyl Yrmak valley, as far at least as Avanos, is filled with a series of almost horizontally bedded neocenes, more or less tufaceous, which gradually rise as one goes east. They are cut off to the south by the valley of the river, and seem on the north to end abruptly against the eocenes. Farther to the east, as one approaches Avanos, the eocenes appear from below and the later deposits make only a narrow cornice against the bluff. Some of this series of beds are more or less water-worn conglomerates, while others are fine-grained tuffs of very even texture. The latter especially have been much used by the troglodytes for excavating houses, churches, and tombs.

South of the river one can see a great confusion of lava-sheets, the spaces between which are taken up by vast masses of tuff. Occasionally the tufaceous matter would become less noticeable,

and they would grade into the usual Neocene conglomerates. The trap-sheets hardly appear north of the river, except at Kara Burun.

Several miles west of Inje Su there is a perfectly flat plain, formed by the vesicular surface of one of the trap-sheets. Nearer to Inje Su itself a stream has cut a deep gorge in this bed, exposing the underlying tuff.

The district between Avanos and Inje Su is the famous troglodyte country, which also extends a long distance to the south, to the west of Mount Argaeus. In the neighborhood of Ürgüb there had evidently been at one time a thick layer of fine homogeneous tuff, capped with a thin trap-sheet, which though harder than the tuff was itself easily weathered and cracked into blocks. Erosion has cut this whole district into a mass of cones of tuff, the higher ones of which are still capped with small blocks of trap. Between these higher ones there are a vast number of shorter cones, whose lava caps have fallen off, and which are fast being eroded away. When the cap falls off it sometimes finds new lodgment at a lower level, and becomes the nucleus of a new shorter cone. Hundreds of the cones have been used by the troglodytes for excavating houses, and many of these are still in use. Where the country is at a little higher level, at Urgüb village, the country is not broken up into separate cones, but there is a large mass of tuff, crowned by a continuous sheet, and terminated to the north with a continuous cliff. The village was originally a system of troglodyte houses excavated in the face of this cliff, but most of the houses have added built façades in more recent times. It is still distinctly a troglodyte village nevertheless.

Beyond Inje Su notes were not taken, but the general character of the country does not change. Tchihatcheff spent considerable time in this district, and gives a long and interesting account of it in the section "trachytes" of his geology of Asia Minor.

THE LACUSTRINES

In this survey I have passed over several sections of the route with hardly a word. These are occupied by the characteristic Neocene (lacustrine) deposits which seem to cover nearly half the surface of Anatolia. They are in general horizontally bedded or

nearly so, sometimes fossiliferous—then generally Pliocene—often formed of the same materials as the eocenes of their district. Still more often they show a more or less characteristic appearance, and may usually be distinguished by their horizontal bedding.

In every place where they come in contact with the trachyte (andesite) deposits, they grade into their tuffs, and are evidently in a general way of the same period. This shows conspicuously at Yuzgad and along the Kyzyl Yrmak near Caesarea.

Here is a list of the places where I found deposits of this type to predominate:

The Sakaria valley near Aktash, and from there to Sivri Hissar.

The Sakaria valley from Sivri Hissar east to the river at Gordium.

The country east of Hammam Merkes and Giaour Kalesi.

The Kyzyl Yrmak valley from Yakshy Khan to Yaghly.

The region about Eyük.

The region beginning just south of Yuzgad and extending the entire length of the Malya Tchöl almost to Hadji Bektash.

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THE VARIATIONS OF GLACIERS. XV[1]

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The following is a summary of the *Fourteenth Annual Report* of the International Committee on Glaciers.[2]

REPORT OF GLACIERS FOR 1908

Swiss Alps.—Of the ninety glaciers which were measured in 1908, fifty-three are in undoubted or probable retreat, one is certainly advancing, and thirteen are possibly advancing. The retreat, therefore, is general. Certain small glaciers have for some years shown signs, more or less definite, of advance. Short glaciers respond more quickly than long ones to the changes in snow-fall, and may make a number of small variations which are not indicated by large glaciers.[3]

Eastern Alps.—A large part of the observations on the glaciers of the Eastern Alps were carried out under the auspices and at the expense of the German and Austrian Alpine Club.

The general retreat was dominant between 1907 and 1908, as it has been for several years past. Only a single glacier, the Wanseeferner, in the Oztetal, has advanced; its advance amounted to 15 meters. The other glaciers showed retreats amounting in some cases to 23 meters.[4]

Italian Alps.—The observations of the Italian glaciers were all the results of private enterprise. All the glaciers observed on the south side of the Alps were apparently in retreat, except possibly a few in the Maritime Alps, which, seen from a distance, had apparently enlarged slightly; but this observation is doubtful.[5]

French Alps.—Many observations on the snow-fall and varia-

[1] The earlier reports appeared in the *Journal of Geology*, Vols. III–XVII.

[2] *Zeitschrift für Gletscherkunde* (1910), IV, 161–76.

[3] Report of Professor Forel and M. Muret.

[4] Report of Professor Brückner.

[5] Report of Professor Marinelli.

tions of glaciers were made under the direction of the Minister of Agriculture.

During the winter of 1907–8, the amount of snow-fall was registered in twenty-seven stations in Savoy; although the snow-fall was less than in the previous year, still the total amount was fairly large. The maximum does not increase with the altitude, as the altitude becomes high; but the observations along this line are still incomplete.

On Mont Blanc the Glacier de Bionnassay, which between 1906 and 1907 had advanced 38 meters, in 1907–8 advanced 17.5 meters farther. The three other glaciers observed in this region had all retreated. The retreat of the Glacier du Tour amounted to 52.5 meters. In the Maurienne three small contiguous glaciers made a slight advance; a fourth glacier, not far distant, had retreated markedly.[1]

Pyrenees.—A number of glaciers observed in this region showed a tendency to a slight advance.[1]

Swedish Alps.—The retreat of the glaciers of Lapland, noticed since 1900, has been confirmed. During the summer of 1908 signals were placed near many glaciers which will lead to more definite results in the future.

Norwegian Alps.—The glaciers of the Jotenheim are in marked retreat, whereas those of the Jostedal and Folgenfon, nearer the coast, show an equally marked advance, the variations between 1907 and 1908 amounting in some cases to about 30 meters.[2]

Canada.—The Illecillewaet Glacier retreated about 40 feet between 1907 and 1908.[3]

Himalaya.—Although no new observations have been made, there are indications that since the survey of 1872–75 the glaciers of Garhwal and Kashmir have retreated considerably.[4]

REPORT OF THE GLACIERS OF THE UNITED STATES FOR 1909[5]

Hallett Glacier, Colorado, shows no change between 1908 and 1909 (Mills).

[1] Report of M. Rabot.

[2] Report of M. Oyen.

[3] Report of Mr. Vaux.

[4] Report of Mr. Freshfield.

[5] A synopsis of this report will appear in the *Fifteenth Annual Report* of the International Committee. The report on the glaciers of the United States for the year 1908 was given in this *Journal* (XVII, No. 7, pp. 667–71).

The glaciers of Mt. Hood, Oregon, show a marked recession since 1906 and they have also decreased in thickness. The White Glacier has receded about 400 meters; Sandy Glacier 100 to 200 meters; Reid Glacier 50 to 100 meters, and Zig-Zag is hardly more than an ice-bank. The glaciers on the north side of the mountain, as seen from the summit, also seemed reduced in size (Montgomery).

Lyman Glacier, near Lake Chelan in central Washington, is still diminishing (Rusk).

Mt. Baker, Washington, the most northerly of the great volcanic cones which rise above the Cascade Range, was surveyed during the summer of 1909 by the United Stated Geological Survey, the party being under the direction of Mr. J. E. Blackburn. Mt. Baker, 10,745 feet high, is covered with ice and snow above an altitude of 5,000 feet, divided into a few separate masses by narrow ridges of rock.

At the lower levels glacier tongues develop, some of which extend to as low an altitude as 3,500 feet. Seven glaciers have been given names, the Roosevelt, Mazama, Wells Creek, Sholes, Park, Boulder Creek, and Nooksack. The last has not been fully explored and may later be divided and receive several names. The ice of these glaciers is especially broken up by large and numerous crevasses. The crater of the mountain, from which steam is still escaping, is about 1,000 feet below the flat snow-covered summit. The moraines in front of the glaciers' ends and the polished and grooved rock along their sides show clearly that they are retreating and diminishing in volume.

Fifteen miles northeast of Mt. Baker rises the spire of Mt. Shuksan, 9,038 feet; a glacier on its western side breaks over a cliff and the ice collects to form a reconstructed glacier at a lower level; this glacier then falls over a second cliff and forms a second reconstructed glacier still lower down (Blackburn).

The United States Coast and Geodetic Survey has published a map of Glacier Bay, and the surrounding area, on a scale of 1/160,000, from surveys made in 1907.[1] It is interesting to compare this map with the earlier one published by the survey in 1899.[2] The

[1] It is numbered 8306 and was published in January, 1910.

[2] No. 3095.

latter was based on surveys made by Reid in 1892, with additions taken from the surveys of the United States Coast and Geodetic Survey and of the Canadian Boundary Commission between 1884 and 1895. At the first glance one is struck by the smaller area covered by the ice, and the correspondingly greater area of bare rock; for instance, the ridge between Casement and McBride glaciers was broken in the earlier map by many arms of ice connecting the two glaciers; the later map shows this ridge as continuous and much broadened. Similar changes are noted in other parts of the map. This indicates not merely the melting of small connecting arms of ice, but also a general lowering of the whole surface of the ice. Dying Glacier at the head of Tidal Inlet has entirely disappeared, and Dirt Glacier, immediately east of Muir Inlet, is not represented on the later map. I am inclined to think that this glacier has not completely melted, but that its very thick covering of moraine has masked its character. Large areas of rock are free of the ice which covered them in 1892.

The ends of the tide-water glaciers have receded greatly (as noted in earlier reports of this series) and allowed the inlets to penetrate farther into the land.

The end of Muir Glacier has receded and divided into two parts, separated by the rocky island which appeared as two distinct nunataks in 1892 about 3 miles from the ice-front. To the north the glacier has receded 8.5 miles. The ice surrounds the water on three sides; bergs are discharged most actively at the northern end of the inlet. To the east the glacier has receded 3 miles and ends in a sloping surface just reaching the water. (Since 1907 this portion has receded still farther and now rests on a sandy beach, where it is forming a terminal moraine Dunann.)

The total increase in the area of the inlet between 1892 and 1907 was 19 square miles.

Carroll Glacier does not seem to have receded, but the Rendu has retreated about half a mile. Grand Pacific Glacier has receded $7\frac{1}{2}$ miles, almost as much as the Muir, and its inlet has increased by 14 square miles. Johns Hopkins has receded 3 miles, increasing its inlet by $5\frac{1}{2}$ square miles, and separating from one of its southern

tributaries, which becomes an independent tide-water glacier. Reid Glacier seems to have receded about $\frac{2}{3}$ mile.

In 1892 Hugh Miller Glacier attained tide-level at two termini; one, on the north, barely reached the water and had a sloping surface; this has retreated about half a mile. The other terminus, on the east, was divided by a rocky mass, north of which the ice resembled the northern terminus but south of which it ended in a cliff discharging bergs. The northern part of this terminus has receded about one mile and has uncovered much rock, about $1\frac{3}{4}$ square miles; the southern part has receded about $1\frac{1}{2}$ miles and the inlet has increased by about 2 square miles. Charpentier Glacier has receded about $1\frac{1}{2}$ miles and its inlet has increased by one square mile. Geikie Glacier has receded about $\frac{3}{4}$ mile and Wood Glacier has greatly diminished in size, though it still seems to reach tide-water as in 1892 without an ice cliff. The total increase in the area of Glacier Bay, as the result of the recession of the glaciers, amounts to about 50 square miles.

Professor Ralph S. Tarr has published a detailed account of the Yakutat Bay Glaciers, with many illustrations and maps, which includes all information regarding these glaciers available at the end of 1906.[1] The remarkable advance of some of these glaciers in the interval between Professor Tarr's visits to them in 1905 and 1906 are carefully considered and ascribed to extraordinary supplies of snow shaken down from the mountains by earthquakes in 1899.[2] This very excellent monograph can receive only a cursory notice here. Professors Tarr and Lawrence Martin organized an expedition under the auspices of the National Geographic Society to revisit Yakutat Bay and Prince William Sound in 1909. Professor Martin has sent me the following outlines of the results of this expedition:

> The National Geographic Society's Alaskan Expedition of 1909 in charge of R. S. Tarr and Lawrence Martin observed the following variations of glaciers.
>
> In Yakutat Bay Hubbard Glacier seemed to be beginning to advance more

[1] "The Yakutat Bay Region, Alaska," *U.S. Geological Survey, Professional Paper No. 64*, Washington, 1909.

[2] Mentioned in an earlier report of this series (this *Journal* [1908], XVI, 54–55).

rapidly; Lucia Glacier was advancing rapidly and overriding a nunatak after semi-stagnation since before 1890; Hidden Glacier had advanced 3 kms. in less than 3 years and had returned to semi-stagnation; Nunatak Glacier was continuing the retreat in progress since 1890, having retreated over $\frac{3}{4}$ km. since 1906 or nearly $5\frac{1}{2}$ kms. since 1895; Turner Glacier had advanced slightly since 1906. The Variegated, Haenke, Atrevida, and the Marvine lobe of Malaspina Glacier had ceased the spasmodic advance which Tarr observed in 1906 and explained, not as climatic, but as part of a glacier flood due to earthquake avalanching. Haenke Glacier, which advanced and became tidal between September, 1905 and June, 1906, had retreated before 1909 so that it no longer discharged icebergs, being fronted by a low gravel cliff. It was once more mantled with ablation moraine, as were large parts of Variegated and Atrevida glaciers and the Marvine lobe of Malaspina Glacier. Our party easily crossed Variegated and Atrevida Glaciers in 1909 in the parts most impassably crevassed in 1906. The advance of three additional glaciers between 1906 and 1909 and the quick return to semi-stagnation in 1909 of the four that were rapidly advancing in 1906 gives additional proof of the earthquake-avalanche hypothesis for certain variations of mountain glaciers.

On the lower Copper River the Miles, Childs, and Baird glaciers were, in 1909, in about the same conditions as when they were seen by Abercrombie in 1884, by Allen in 1885, by Hayes in 1891, and by Schrader in 1900. Parts of Miles and Baird glaciers have been stagnant and forest-covered for at least twenty-five years. Five miles of railway track has been laid on Baird Glacier. Childs Glacier seems to be advancing and forcing Copper River eastward, according to Johnson. The rate of movement near its northern margin in July, 1909 was about 4 feet a day. During the last half of July, 1909, ablation lowered the surface of Childs Glacier at the rate of 7 inches a day.

In eastern Prince William Sound, Valdez Glacier is retreating, as it has been since 1898 excepting the slight advance between 1905 and 1908 recorded by Grant. Shoup Glacier has been retreating since 1898 except for a slight advance, perhaps, in the spring of 1909. Columbia Glacier was continuing the advance observed by Grant in 1908 and early in July, 1909. The eastern margin had advanced, before August, 1909, making a decided lobation, but not reaching the forest along the whole margin. The western margin had advanced more than 800 feet up to the forest of Gilbert's maximum of 1892, as was also the case at Heather Island where the middle of the glacier was destroying the forest in August, 1909.

The United States Geological Survey has published a bulletin[1] containing a short account of the glaciers of the Wrangell

[1] F. H. Moffit and Adolph Knopf, "The Mineral Resources of the Nabesna–White River District, Alaska, with a Section on the Quaternary by S. R. Capps," *U.S. Geol. Survey, Bull. No. 417*, Washington, 1910.

Mountains, Alaska, and a topographic map of the region; and from it we draw the following information:

> A very important feature of the Wrangell Mountains is the great ice cap that occupies the crest of the range and that has its greatest development in the region around Mount Wrangell. From the periphery of this great feeding-ground valley glaciers extend in all directions down the more important drainage lines.

The Nabesna and the Chisana are by far the largest of these glaciers. The former is about 55 miles long and has an area of about 400 square miles. The latter is 30 miles long with an area of 135 square miles. There are many smaller ice tongues, and even small glaciers independent of the main ice cap.

> The St. Elias Mountains, south of White River, are snow-capped in much the same way as the Wrangell Mountains. Most of the mountain range is unexplored, however, and the extent and area of the ice field is unknown. All the more important tributary valleys to the north are occupied by valley glaciers, the largest and best known of which is the Russell Glacier, at the head of White River. The main lobe of ice in the head of the White Valley is between 6 and 7 miles long and about $2\frac{1}{2}$ miles wide, and most of the ice moves in a northeast direction. A small crescentic lobe, however, moves westward into the head of Skolai Creek.

Formerly the glaciation was much more extensive, but very little information is available to determine what changes are taking place at present. In 1891 the western terminus of Russell Glacier was a smooth slope, but in 1909 it was a wall of ice from 25 to 75 feet high. This certainly indicates an advance of the ice, but at the northeastern terminus the ice passes into the moraine without a clear line of demarkation, indicating a slow, gradual retreat. The Nizana Glacier was formerly crossed by prospectors going to the White River region, but it has become so crevassed as to be practically impassable, which suggests an advance of the ice.

Reviews

Testing for Metallurgical Processes. By JAMES A. BARR. San Francisco: The Mining and Scientific Press; London: The Mining Magazine, 1910. Pp. 216. $2.00 delivered.

This book, which is based on a course of lectures given by Mr. Barr at the Michigan College of Mines, is a laboratory manual for the student of metallurgy and for the mining engineer. The treatment differs from that of the textbooks on metallurgy in that the methods for testing are fully treated and minute details for many of the operations are given. It is designed not to take the place of the textbooks on metallurgy but to supplement them. The subjects treated include amalgamation, chlorination, cyaniding, concentration, smelting, calculation of lead and copper slags, cost data, etc. The treatment, while condensed, is exceptionally clear. The work should be appreciated by students, mining chemists, and engineers. W. H. E.

Economic Theory with Special Reference to the United States. By HEINRICH RIES. 3d ed. New York: Macmillan, 1910. Pp. 589.

The third edition of this work is revised and greatly amplified. The treatment of the non-metallic minerals, which covers about 300 pages, is well arranged, and the data are clearly presented. The coal fields of the United States are described in considerable detail and the occurrences of other hydrocarbons are mentioned or briefly described. Chapters are devoted to building stones, clays, limes and cements, salines, gypsum, fertilizers, abrasives, minor non-metallic minerals, and underground waters. The illustrations and text figures are well chosen and clearly executed. The references are numerous, but are placed at the end of each chapter, a practice which, though saving space, renders them less accessible to the reader or student. The treatment of the metals is superior to that of previous editions. Although the book is intended primarily as a text, it should serve a useful purpose as a work of reference to the engineer or geologist who wishes general information regarding the occurrence and uses of certain minerals and the literature of the subject. W. H. E.

The Geology of New Zealand. By JAMES PARK, Professor of Mining and Mining Geology in the University of Otago. Pp. 488, with 145 illustrations, 27 plates, and a colored geological map. London: Whitcombe & Tombs, Limited, 1910.

This new work is welcome to the geologic reader because it gives in organized, systematic, and relatively brief form a general view of the geology of a country whose geologic literature is otherwise scattered and to most geologists not readily accessible. It must also be acceptable to the teachers and students of New Zealand in that it gives them a view of geological history founded on the formational record of their own land. The work combines some of the features of a synoptic governmental report with those of a textbook. It was written originally for the Department of Mines, but only a part of it was published by the government—a fact which probably accounts for a seemingly disproportionate treatment of certain topics as compared with others, and also some lack of continuous progression under the control of a well-chosen scheme.

Detailed descriptions of the various formations comprise the first portion of the work. Each series is discussed first under the head of distribution, thickness, and age; then the faunas and floras are taken up, followed by the economic minerals and the igneous activity of the time. As might not unnaturally be expected in a country where even today the glaciers are such splendid spectacles, the Glacial Period has received much fuller treatment proportionately than the other periods. In an interesting discussion upon the excavating power of glaciers, the assertion is made that it is certain that ice can only excavate its bed when the pressure of its mass exceeds the ultimate crushing strength of the bed rock, and that the pigmy valley glaciers of today are incapable of excavating their beds. That glaciers, even those of the small valley types, may be active eroding agents seems to find much less favor with the English school of geologists than with the American.

The last portion of the book is devoted to economic geology. Naturally the greatest emphasis and fullest treatment are given to the very extensive coal fields and the important gold deposits, both of which have long attracted notice.

A very welcome feature of the book is the closing chapter, which presents a complete bibliography of the geology of New Zealand covering 56 pages. This book places the principal facts of New Zealand geology at the disposal of any geologist who reads English.

R. T. C.

Topologie. Étude du terrain. Par le GÉNÉRAL BERTHAUT. 2 vols., quarto, pp. 674; 265 full-page topographic maps; 65 text figures. Paris: Service Géographique de l'Armée, 1909.

This title covers a masterly philosophical treatise upon the evolution of land forms. The presentation is founded upon a thorough analysis of the geologic agencies which co-operate to form and to alter the surface features. The different classes of topographic features are described in the light of the various deformative and physiographic processes to which they owe their origin. These processes are taken up successively, and as the peculiarities and characteristics of the resulting topography are minutely described, they are vividly illustrated by the introduction of topographic maps. The subject is further developed from a discussion of these maps, which are so numerous as to constitute one of the leading attractions of the work. Most of the maps are selected from the topographic surveys of France and the French possessions in North Africa, with occasional sheets from the Swiss Alps, Norway, and the United States.

R. T. C.

La sécurité dans les mines. Étude pratique des causes des accidents dans les mines et des moyens employés pour les prévenir. By H. SCHMERBER. Paris: Ch. Béranger, éditeur, 1910. Pp. 659; figs. 589.

Now that the people of this country have been awakened to the need of greater safety in coal mining and efforts are being made to better the mining conditions, this new work on the engineering phase of the problem is very timely. It should be understood, however, that the geological and strictly scientific aspects of the problem of mine explosions scarcely enter at all into the author's treatment and hence the book contains little of interest to geologists as such. But as an engineering work, which in truth is all that it attempts to be, it is an admirable treatise.

R. T. C.

Leading American Men of Science. Edited by DAVID STARR JORDAN. New York: Henry & Holt Co., 1910. Pp. 471, with 17 portraits.

This volume is made up of biographical sketches of seventeen men of the past selected as leaders in American science by a zoölogist of eminence. The selection embraces an astronomer, a chemist, a geolo-

gist, four zoölogists, two ornithologists, two paleontologists, one anatomist, one botanist—ten out of the seventeen from the biological group—and four physicists. The individuals chosen and the authors of the essays are as follows:

Benjamin Thompson, Count Rumford, Physicist. By Edwin E. Slosson.
Alexander Wilson, Ornithologist. By Witmer Stone.
John James Audubon, Ornithologist. By Witmer Stone.
Benjamin Silliman, Chemist. By Daniel Coit Gilman.
Joseph Henry, Physicist. By Simon Newcomb.
Louis Agassiz, Zoölogist. By Charles Frederick Holder.
Jeffries Wyman, Anatomist. By Burt G. Wilder.
Asa Gray, Botanist. By John M. Coulter.
James Dwight Dana, Geologist. By William North Rice.
Spencer Fullerton Baird, Zoölogist. By Charles Frederick Holder.
Othniel Charles Marsh, Paleontologist. By George Bird Grinnell.
Edward Drinker Cope, Paleontologist. By Marcus Benjamin.
Josiah Willard Gibbs, Physicist. By Edwin E. Slosson.
Simon Newcomb, Astronomer. By Marcus Benjamin.
George Brown Goode, Zoölogist. By David Starr Jordan.
Henry Augustus Rowland, Physicist. By Ira Remsen.
William Keith Brooks, Zoölogist. By E. A. Andrews.

Students of geology will be most interested in the lives of Dana, Marsh, and Cope, the leading events of whose fruitful scientific careers are clearly set forth.

R. T. C.

Geology and Ore Deposits of Republic Mining District. By JOSEPH B. UMPLEBY. Washington Geological Survey, Bulletin No. 1. Pp. 65; figs 5; pl. 13. Olympia, 1910.

Physiographically the Republic mining district in northeastern Washington appears to be an extension of the Interior Plateau of British Columbia and to be allied in Tertiary history with it. At the same time it seems to belong to a different physiographic unit from the central Cascades.

The oldest rocks exposed in the Republic district are metamorphic, and are provisionally assigned to the Carboniferous. In early or middle Mesozoic times there occurred great batholithic intrusions of granodiorite. Following these came a great period of erosion lasting until the middle of the Tertiary. During this time there was developed an Eocene peneplain which was lifted and trenched before the end of

the Oligocene. The rocks next in order are dacite flows of Oligocene age. The remaining Tertiary history is written in several periods of igneous activity—andesite flows, intrusive latite porphyries, and a basaltic eruption during the Pleistocene.

The total bullion production of the camp since the first discovery of ore in 1896 has been about $2,000,000, of which approximately 90 per cent has been gold and the remainder silver. The veins are thought to be genetically related to the latite porphyry intrusion and are made up of quartz, chalcedony, opal, calcite, and adularia, carrying inconspicuous amounts of pyrite and possibly gold, in association with antimony, sulphur, and selenium.

Though the deposits at Republic are not altogether like any others known in the United States, they most closely resemble the lodes of the Great Basin province. Their striking feature is the great amount of selenium in the ores, and they are thus best correlated with Tonopah and Goldfield, the only other camps in the United States known to produce selenium ores.

The report closes with a detailed description of the principal mines of the district, of which the New Republic mine is easily the leader.

R. T. C.

Notes on Explosive Mine Gases and Dusts with Special Reference to Explosions in the Monongah, Darr, and Naomi Coal Mines. By Rollin Thomas Chamberlin. U.S. Geol. Surv. Bulletin 383.

The results of a series of experiments carried out by the author throw new light on the nature of the explosive material and on the conditions governing explosions in coal mines, and should be of great practical, as well as scientific, value. As soon as possible after the explosions in the mines mentioned, samples of the mine atmosphere were collected and analyzed. Another series of experiments was carried out to determine the probable condition of the gas in the coal, whether (1) imprisoned in minute cavities, (2) occluded or dissolved in the substance of the coal, or (3) the result of slowly operating chemical processes. This was done by studying the rate of liberation of gas (1) from coal bottled in vacuum, (2) from crushing the coal, and (3) from heating the coal. A careful study was also made of the position and nature of the dust in passage-ways and on timbers in the mines after the explosions.

It is concluded that if methane were the sole explosive gas, only local explosions near the face of the coal could result. Coal dust is present, however, in large quantities and can under proper conditions become explosive. The chief restraining agent on dust explosion is dampness, and the presence of a high proportion of non-combustible shale dust. A great reduction of the moisture in mine atmospheres results from the incoming of cold air at the beginning of winter, and it is observed that most of the great explosions have been at that time.

It is a general belief that old dust exposed for a long time to the air is more dangerous than fresh dust, but the author shows by experiment that this belief is erroneous, and that fresh dust is the more explosive.

E. R. L.

Reconnaissance of the Book Cliffs Coal Field between Grand River, Colorado, and Sunnyside, Utah. By G. B. Richardson. U.S. Geol. Surv. Bulletin 371.

The field forms a part of the south rim of the Uinta basin, around whose margin the outcrops of coal-bearing rocks can be traced for more than five hundred miles. Three formations of Cretaceous rocks are mapped: the Dakota sandstone lying unconformably on Morrison beds, the Mancos shale of Colorado and Montana age, and the Mesaverde formation which is overlain unconformably by Wasatch beds. The Mesaverde is partly marine and partly non-marine, the marine part showing close similarity to the upper Mancos shale and the non-marine to the Laramie. The age is placed as pre-Laramie, the Laramie epoch being supposedly represented by the unconformity above.

Coal of good quality occurs in the lower part of the Mesaverde formation in some localities. Several beds are present, but no single bed has been traced for more than a few miles. The coal of the region is little developed.

E. R. L.

Cenozoic Mammal Horizons of Western North America. By Henry Fairfield Osborn, with *Faunal Lists of the Tertiary Mammalia of the West* by William Diller Matthew. U.S. Geol. Surv. Bulletin 361.

This report is primarily a correlation of the mammal-bearing horizons of the Cenozoic with one another and with those of Europe, with a brief characterization of each horizon. In the Tertiary, six faunal phases are

recognized, containing eighteen subdivisions, while a seventh phase belongs to the Pleistocene. Three faunal phases containing seven subdivisions belong to the Eocene, the fourth phase, containing seven subdivisions, extends through the lower Miocene, the fifth phase extends through the middle and upper Miocene, and the sixth through the Pliocene. The conclusion is that North America promises to give a nearly complete and unbroken history of the Tertiary in certain regions, though much work still remains to be done. The chief remaining gap is now in the Pliocene stratigraphy.

E. R. L.

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THE

JOURNAL OF GEOLOGY

FEBRUARY–MARCH, 1911

THE SOUTHERLY EXTENSION OF THE ONONDAGA SEA IN THE ALLEGHENY REGION[1]

E. M. KINDLE

It is proposed in this paper to present some of the evidence which calls for a distinct modification of the current conception of the extent of the Onondaga sea in the eastern part of the United States. Before submitting the new data the reader's attention will be invited to certain features of the previously recorded faunal and lithologic facts relating to the Onondaga sediments which, in the writer's opinion, have led to some misconceptions regarding the character and extent of the Onondaga sea in the eastern states.

The Onondaga fauna as developed in the states of New York, Ohio, Indiana, and Kentucky was one of the first of our Paleozoic faunas to be studied and described. The reports of the state surveys of these states, supplemented by numerous unofficial papers in which this fauna has been recorded and illustrated, have made it one of the best known of the Paleozoic faunas. It is a noteworthy fact, however, that all of the various contributions to our knowledge of this fauna have dealt with a nearly pure limestone fauna. If one were to seek a comprehensive idea of the character of the Onondaga sea and its sediments from the published descriptions of the fauna and the limestones holding it, he would get the conception of a sea in which only limestones were deposited. To any-

[1] Published by permission of the Director of the United States Geological Survey.

one who admits that the factors controlling marine sedimentation were essentially the same in Paleozoic and recent times, a Devonian sea in which only calcareous sediments accumulated is a manifest absurdity. We know of no continental or other seas in which there are not a variety of types of sediment accumulating simultaneously. Papers which have undertaken to deal with this fauna in a large way and weld its evidence into the new science of paleogeography have naturally been influenced by the fact that the only faunas described from the Onondaga sea were limestone faunas. Translated into the form of a paleogeographic map this class of evidence taken alone gives us a sea whose outlines inclose only limestone sediments. This was a serious defect in Professor Charles Schuchert's first map of the Onondaga sea.[1] The shorelines given by it for the Onondaga sea in the central states inclosed a sea from 100 to 300 miles in width. All of the known Onondaga deposits included by the shorelines of the map are limestones. The recently published map of the middle Onondaga by Professor Schuchert[2] shows improvement in this respect, since it includes the shales and argillaceous limestone bands holding the Onondaga fauna which was discovered in central Pennsylvania by Charles Butts and determined by the writer. The later map, however, still gives us a conception of the Onondaga sea far from that which the writer's recent studies in the Allegheny region appear to demand. The writer's criticism, it may be stated here, is directed primarily, not to Professor Schuchert's map, which incorporated all of the positive evidence available at the time of its preparation, but at the incompleteness of the evidence in a region where it might be expected to be fairly complete.

In order to ascertain to what extent recorded evidence and opinion will enable us to reconstruct the shorelines of the Onondaga sea within the limits of the eastern states so that they will appear consistent and rational with reference to the character of the known deposits of that sea, we may consider briefly the principal sources

[1] Charles Schuchert, "On the Faunal Provinces of the Middle Devonic of America and the Devonic Coral sub-Provinces of Russia, with Two Paleographic maps," *Am. Geol.* (1903), XXXII, 137–62, Pl. 20.

[2] Charles Schuchert, "Paleogeography of North America," *Bull. Geol. Soc. Am.*, XX (1910), 75.

of its sediments. The comparatively thin mass of sediment which accumulated during the whole of the Devonian in the central states affords satisfactory evidence that the land area adjacent to the Devonian sea on the west had slight relief, and furnished comparatively little sediment at any time during the Devonian. On the east side of the Devonian sea, however, physiographic conditions were very different. Willis[1] has shown that during much of the Devonian period there lay immediately southeast of the Allegheny region the highlands of Appalachia. This old land area furnished to the interior Devonian sea of the Appalachian region, between the beginning of the Hamilton epoch and the close of the Devonian, a mass of sediments which, if restored upon a sea-level plain of Appalachia, "would constitute a mountain range closely resembling in height, extent, and mass the Sierra Nevada of California."[2]

According to the prevailing view[3] this fertile source of Devonian sediments was elevated at the close of the Oriskany to such an extent that throughout Onondaga time the Allegheny region was a land area. Such elevation, if it occurred, must have resulted in accelerated erosion in the Devonian highlands, and in an increased volume of sediments in the Onondaga sea. If this hypothetical uplift occurred, it could not have failed to have been registered by a great thickness of coarse clastic sediments in the narrow Onondaga sea which, as outlined by Schuchert's map, extended as a narrow belt across the adjacent portions of the present states of Kentucky, Indiana, and Ohio. Instead of such coarse clastics we find in these states, as previously noted, only limestones representing sedimentation near the eastern shore of the Onondaga sea as outlined by Schuchert.[4] The utter impossibility of harmonizing the pure limestone deposits representing the Onondaga in the Ohio valley with this currently accepted theory of diastrophism in the Allegheny region would appear to be a sufficient reason for discarding it. If, however, we assume that Appa-

[1] *Md. Geol. Survey, Special Publication*, Vol. IV, Pt. I, pp. 61–62.

[2] *Ibid.*, p. 62.

[3] Charles Schuchert, "Paleogeography of North America," *Bull. Geol. Soc. Am.*, XX (1910), 492.

[4] *Ibid.*, Pl. 75.

lachia was not elevated and the Devonian shoreline was not pushed westward at the initiation of Onondaga time, we would still expect as a probability non-calcareous sediments to predominate in the eastern portion of the Onondaga sea. That portion of the Onondaga sea adjacent to the land area which furnished 10,000 feet of non-calcareous Devonian sediments in post-Onondaga time would be likely to acquire chiefly non-calcareous sediments even in an epoch so favorable to calcareous sedimentation as the Onondaga.

A considerable mass of paleontologic and stratigraphic data which has been gathered by the writer shows that Onondaga sediments are present in the Allegheny region and are mainly of this non-calcareous type, as might have been expected from theoretical considerations. The recent discovery of an Onondaga fauna in the Allegheny region which occurs in a series of drab or dark shales and thin interbedded argillaceous limestones thus very materially supplements the hitherto one-sided character of the available data relating to the nature of the fauna and sediments of the Onondaga sea. The sediments holding this fauna are of such a character as we might have expected to be accumulating on some portion of the Onondaga sea floor if we may judge by analogy with the processes of sedimentation now in operation in the largest continental seas. Since this fauna will be described and figured in a forthcoming bulletin of the United States Geological Survey, only the most general facts regarding it will be presented here. The fauna comprises more than one hundred species. The correlation of this Allegheny fauna with the New York Onondaga fauna is based primarily upon the presence in it of such well-known species as *Anoplotheca acutiplicata*, *Rhipidomella vanuxemi*, *Spirifer acuminatus*, and *Odontocephalus aegeria*. The great abundance and general distribution of the first named of these species is a conspicuous characteristic of the fauna. In point of abundance and wide distribution in this argillaceous facies of the Onondaga, *Anoplotheca acutiplicata* is as prominent as is *Spirifer acuminatus* in the well-known calcareous facies. It is interesting to note in this connection that while *Anoplotheca acutiplicata* is a familiar species in the Onondaga limestone of eastern New York comparatively near the region under discussion, it is unknown in the more westerly areas

of the limestones of Onondaga age in Ohio, Indiana, and Illinois. Its occurrence in typical Onondaga limestone only in an area which is nearly adjacent to the region of the shaly facies of the formation suggests that the latter type of sediments furnished its normal and most congenial habitat. *Spirifer acuminatus*, on the other hand, does not extend very far to the southward into the region occupied by the argillaceous facies of the Onondaga. Other Onondaga species, however, like *Odontocephalus aegeria*, appear to be equally adapted and distributed in both types of sediment.

Some of the stratigraphic data relating to this fauna may be very briefly summarized as follows:

The calcareous shales holding this fauna are generally preceded in the sections by the Oriskany sandstone and always followed by the dark fissile and comparatively barren shales of the Marcellus. These two limiting formations exhibit in general essentially the same lithologic characters throughout Pennsylvania, Maryland, West Virginia, and much of Virginia as in New York. Both are, however, much thicker in this more southerly region than in the type region of the Onondaga limestone in New York. In the Helderberg mountain region the Onondaga and the Hamilton faunas are separated by 300 feet of comparatively barren dark Marcellus shale, and in western New York by about half this thickness, while in Pennsylvania and southward these shales often have a thickness of more than 500 feet.

While the succession from the Onondaga fauna to the Marcellus fauna above is a uniform one throughout most of the Allegheny region, as it is in New York, the succession at the base of the fauna is not everywhere precisely the same. In most of the territory the Onondaga beds rest upon the Oriskany, but in some of the Pennsylvania sections they immediately follow beds representing the Esopus shale. In respect to its underlying formation, however, the Onondaga shows less variation than in New York, where, in different areas, it is found to follow the Manlius, Oriskany, Esopus, and Schoharie. Thus, we find that this fauna occupies in the Allegheny region the same relative position in the succession of faunas as the Onondaga fauna does in the standard sections of New York. The stratigraphic evidence, therefore, coincides with the paleontologic

evidence already briefly cited in pointing to the Onondaga age of the fauna. We may now consider the bearing of the data which have been cited on the modification of the current conception of the eastern shoreline of the Onondaga sea in the eastern United States.

The Onondaga formation extends scarcely south of the Delaware River according to most of the papers dealing with the stratigraphy of the Devonian in the Allegheny region, thus giving it a north-south extension of scarcely 200 miles. This comparatively insignificant southerly extension of a fauna which is so persistent in a westerly direction seems more surprising when it is recalled that all of the other faunas characterizing the major divisions of the New York Devonian section have with one or two exceptions been traced southward from New York entirely across Pennsylvania. Thus it is seen that the prevailing conception of the Onondaga formation and fauna, which presumes their absence south of New York, gives to it an anomalous position as compared with the other important formations of the Devonian section of New York. The evidence which the writer has gathered during three seasons of field work in the Allegheny region indicates that the southerly extension of the Onondaga fauna is quite comparable in distance with its westerly extension. The field studies of the writer have shown that the Onondaga fauna in the Allegheny region extends far to the southward of the area in which nearly pure limestones were deposited during Onondaga time into a region where shale-forming sediments partially or completely dominated those of calcareous type. This fauna has been found in nearly all the sections studied from New York to Tennessee.

The direct bearing of these new data on the paleogeography of Onondaga time is obvious. Its incorporation involves the extension of the eastern shoreline of the Onondaga sea in a southwesterly direction from southeastern New York to the eastward of the Allegheny region instead of far to the westward of it, as now drawn, across the states of Ohio, Indiana, and Kentucky. In the light of this new evidence it appears that the eastern shoreline of the Onondaga sea trended southwesterly across north-central New Jersey and southeastern Pennsylvania. It probably traversed the

states of Maryland and Virginia near the present axis of the Blue Ridge Mountains. From southwestern Virginia this shoreline appears to have trended westerly not far from the Kentucky-Tennessee line as far as the valley of the Tennessee River where it resumed its southerly trend. This revision of the shorelines of the Onondaga sea gives, instead of the Cincinnati peninsula of Schuchert's map, a Cincinnati island. This, and probably other smaller islands, interrupted the continuity of the Onondaga sea, which, in the region of the Ohio valley, reached a maximum width of about 500 miles from northwest to southeast.

THE MISSISSIPPIAN-PENNSYLVANIAN UNCONFORMITY AND THE SHARON CONGLOMERATE[1]

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There exists in northern Ohio a well-defined boundary between the strata of the Mississippian and Pennsylvanian ages, a boundary marked by a pronounced unconformity. The upper limit of the Mississippian is the top of the well-known Cuyahoga formation, and the lower limit of the Pennsylvanian is the bottom of the equally well-known Sharon conglomerate.

So far as the writer is aware the Sharon has been generally regarded as a formation of general extent around the northern and northwestern border of the Appalachian coal basin, and resting upon the Mississippian in a continuous sheet except where removed by erosion.

Field work the past summer in Mahoning, Trumbull, Portage, Summit, and Geauga counties has revealed some facts that lead the writer to believe that the Sharon conglomerate is not the simple formation that it has been thought to be, and that it has a setting of unusual interest.

Following its outcrop from place to place, the formation is found to change in structure quickly, to disappear suddenly, and to be absent over considerable areas, letting later rocks form the contact with the Cuyahoga. Where its development is greatest, it lies in troughs of the Cuyahoga. Further, it is found to occur in belts having a more or less north-and-south direction, and these belts, in places at least, are not now and never have been connected from east to west. This is due, in part at least, to the fact that the conglomerate lies between ridges of the Cuyahoga, and not alone to post-Pennsylvanian erosion.

[1] Published by permission of Dr. J. A. Bownocker, state geologist of Ohio. Presented at the twentieth meeting of the Ohio Academy of Science, Akron, November 25, 1910.

This manner of occurrence calls attention to the surface upon which the Pennsylvanian rests. Whatever may be the case elsewhere, the writer believes that greater erosion of the upper Mississippian occurred in northern Ohio than is generally known. Instead of the Sharon resting upon a nearly uniform plane, it is found that the surface of the Cuyahoga has a relief of nearly 200 feet, and it is significant that where the depressions are greatest, the Sharon is also thickest. The regional or belt-like occurrence of the conglomerate, and its apparent relationship to depressions in the Cuyahoga, along with the structure and variability of the stratum, have led the writer to the conclusion that these depressions are creek and river valleys, and that the conglomerate is a deposit of stream gravels, and that the overlying sandstones of the Pottsville are, to a greater or less extent, river and delta deposits.

Some of the data on which this view is based are added. Valleys in the Cuyahoga formation are of general occurrence. The most conspicuous and deepest one so far found may be noted in some detail. This valley lies in the eastern edge of Portage and Geauga counties, about half-way between Akron and the state line, and its course is roughly north and south. At Akron, the top of the Cuyahoga formation lies about 940 above sea; due east, at Mineral Ridge, west of Youngstown, at 962; at Newton Falls, between these two points, and 5 miles north of the Akron-Mineral Ridge line, it lies below 850, or about 100 feet lower than to the east or west. If such a line be drawn from east to west half-way between Akron and Cleveland, the same depression in the Cuyahoga is again found. At Brandywine Falls, 15 miles north of Akron, the top of the Cuyahoga formation lies at 1,040; near Howland Springs, due east of Brandywine, at 1,044; and at Nelson Ledges between these two points at 956, or again nearly 100 feet lower.

Another east and west comparison may be cited. At Burton, due east of Cleveland, the top of the Cuyahoga lies at 1,090 and due east on the state line at 1,190, or 100 feet higher. These three middle points—Newton Falls, Nelson Ledges, and Burton—are in line, roughly, north and south, and are clearly in a depression of the Cuyahoga formation, since rock of this formation lies higher both to the east and west. Further, this depression cannot be

assigned to a syncline, as is proven by the nearly horizontal position of the Berea in the same direction. It is worthy of note that the Sharon and overlying sandstones in the line of this old valley reach their greatest development in Ohio, and form a great body of conglomerate and sandrock extending southward from southern Lake County, through Geauga and Portage counties, at least as far south as northern Stark County. The evidence is strong that the conglomerate and overlying sandstones in this great ridge are stream deposits, and will be discussed later.

It may be objected that the distances involved in the three lines across this supposed valley are of such length as to be of doubtful value. Data are at hand, however, which confirm fully what the three lines of elevation show. At Brandywine the Sharon base is 210 feet above the Berea; due east at Nelson Ledges only about 75 feet; near Newton Falls only about 75 feet; but on the state-line nearly due east of Nelson Ledges nearly 300. The meaning of these figures is clear, and shows deep erosion, which is still further confirmed by the presence of hills of the Cuyahoga in the very region in which the erosion was greatest. As stated above, the top of the Cuyahoga near Newton Falls lies below 850 and in $2\frac{1}{4}$ miles north rises to 1,040 above sea-level. It therefore forms a hill at least 190 feet high, with no trace of the Sharon or overlying sandstones. Within $3\frac{1}{2}$ miles to the northwest from this hill, and in a direction opposed to the dip, the surface sinks to 919 feet at least. At Nelson Ledges the conglomerate is about 75 feet thick, and one solid mass from bottom to top. It appears to the observer that it may be expected to continue for miles to the north, but instead it thins out quickly on the steep slope of another Cuyahoga hill, which rises from 956, at the base of the Ledge, to 1,107, a rise of 151 feet in 1 mile. Within 2 miles to the northwest from this hill, the surface drops again to 990, or 117 feet, as seen in the Parkman gorge. From this point the surface rises again to the northeast, 180 feet in $2\frac{1}{2}$ miles, then falls toward the northwest. At Newton Falls, there is a like rise toward the northeast from below 850 to 941, in about 3 miles. Now all points which show these old hills are on or near the eastern margin of this rock ridge, and in every case

bear evidence of a more or less westerly slope toward the ridge. They are clearly hills bordering a valley, and are conclusive evidence of former dissection to a depth of nearly 200 feet. This same hill and valley topography of the Cuyahoga is found all through eastern Trumbull and northern Mahoning counties, with the conglomerate often absent, and with the Sharon coal lying close above the Cuyahoga.

One of the finest exposures of the unconformity occurs in Mineral Ridge, south of Niles, and near the Mahoning-Trumbull line. A deep east-and-west ravine cuts through a north-and-south Cuyahoga ridge finely exposing the contact, showing the horizontal shale and flaggy layers of the Cuyahoga, overlain by the steeply inclined strata of the Pennsylvanian. The slope of the Cuyahoga is toward the east, and at an angle of about 25°, is ragged or stair-step like, and is directly overlain by 2 or 3 feet of crude, mixed sandstone, without lamination or bedding planes, which grades quickly into a bluish shale, then to a carbonaceous shale which carries the well-known and formerly much-worked bed of iron ore. The ore is a highly ferruginous limestone, which is certainly the Lowellville limestone. Directly above the ore is a bed of coal—the Mineral Ridge coal—which lies only 8 feet above the Cuyahoga. The sandstone, shale, ore, and coal all lie at the same steep angle above the Cuyahoga.

I have stated above that the Sharon conglomerate bears evidence of being a stream deposit. This appears from its position, its constitution, and its structure. In some places it is little else than a mass of quartz pebbles which range in size from coarse sand to half the size of the fist. Commonly the stratum is an alternation of sand beds and pebble layers, of constant variation both horizontally and vertically. Bottom-set, fore-set, and top-set beds are common. The sudden change from sand to gravel, and the very variable structure of the sand beds, all of which may be repeated several times in a single rock face, can be accounted for only by stream action. There is not any feature of the conglomerate that stream action does not produce. On the other hand, the writer is unable to conceive of any other agency capable of producing a like stratum.

It will be interesting to note the most exaggerated conglomeratic development found. It occurs at the base of the Sharon as exposed in the gorge at the village of Parkman, Geauga County. Lying directly upon the Cuyahoga, and representing a stream velocity of probably 3 miles an hour, is a 3-foot bed composed not of pebbles alone, but of cobble stones, or pieces of flagstone from the Cuyahoga, some angular, some rounded and flat and well worn, 2 to 3 inches thick and more than a foot in diameter, standing and lying in all positions and mixed with sand and pebbles. It is a veritable picture of the stones and gravel and sand all mixed that we have all seen many times on the inside curve of streams. A more convincing evidence of stream deposit in former ages can hardly be found.

It is worthy of note here that two distinct stages in the deposition of the Sharon are displayed in this gorge. At 10 or 12 feet above the base the conglomeratic character is entirely absent, a rather fine soft sandstone occurs, the top of which is quite undulating, as if eroded. Resting directly upon the undulating surface, with a sharp line, is the massive conglomeratic rock characteristic of the Sharon. The transition is sudden and very conspicuous and is well shown at a number of points in the gorge.

At Nelson Ledges the base of the conglomerate lies at 956, and $\frac{1}{2}$ mile west conglomerate is found at 1,160 above sea. This whole thickness of 204 feet is not to be assigned to the Sharon, however. Overlying sandstones are conglomeratic in this locality and sufficiently so to be mistaken easily for the Sharon itself. Two miles south of this point and about $\frac{3}{4}$ mile south of Nelson village at Ledge Haven Mill conglomerate rock is found on Tinker Creek. There are clearly two stages of conglomerate formation here. The bed of the creek below the fall is conglomerate of unknown thickness. It is directly overlain by 5 to 6 feet of dark gray sandy shale and this is overlain in turn by 30 to 40 feet of conglomerate. The top of the lower stratum lies at 952, as seen at the foot of the fall beside the mill. The shale stratum is strongly suggestive of the horizon of the Sharon coal. It also strongly suggests relationship to the two-stage phase of the conglomerate observed in the Parkman gorge. At the latter place this transition occurs at a level of about

1,000 feet above sea, and is nearly 5 miles north of the above mill, and when dip is taken into account the probability is very strong that the phenomena seen at the two places belong to the same horizon.

A quite singular feature occurs in this shale at the fall. Near its middle, and imbedded in it, lies a lenticular mass of conglomerate a foot thick and probably weighing nearly a ton. It contains large quartz pebbles, much pyrites of iron, and an impression of a calamite. How was it transported to this place where only fine sediments were being deposited? Where did it come from, and from what rock formation was it detached? For the conglomerate beneath must have been only a stratum of sand and gravel when it was deposited. In central Ohio three other formations intervene between the Cuyahoga and the base of the Pennsylvanian, the lower one of which—the Black Hand—is known to be conglomeratic in part. Is this conglomerate block imbedded in this shale a remnant of the Black Hand which once may have overlain the Cuyahoga in northern Ohio, and was completely removed by erosion before the close of the Mississippian? These are questions to which only further study may reveal the answer.

THE WICHITA FORMATION OF NORTHERN TEXAS[1]

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With discussions of the Fauna and Flora by
GEORGE H. GIRTY AND DAVID WHITE

INTRODUCTION

The geology of the "Red Beds" area of northern Texas has long been recognized as one of the perplexing problems of North American geology. The interest aroused by the discovery in these beds of a fauna which was regarded by Cope, C. A. White, and others as Permian has brought forth a number of papers bearing on this region, most of which are based on transient visits in search of fossils, generally with scant attention to the detail of stratigraphy.

This paper is based upon investigations made in connection with the study of underground water conditions for the United States Geological Survey during the field seasons of 1906 and 1907. The collections of invertebrate fossils made in the course of the investigations were submitted to Dr. George H. Girty of the Survey, who also had for study additional materials collected by E. O. Ulrich in former years.

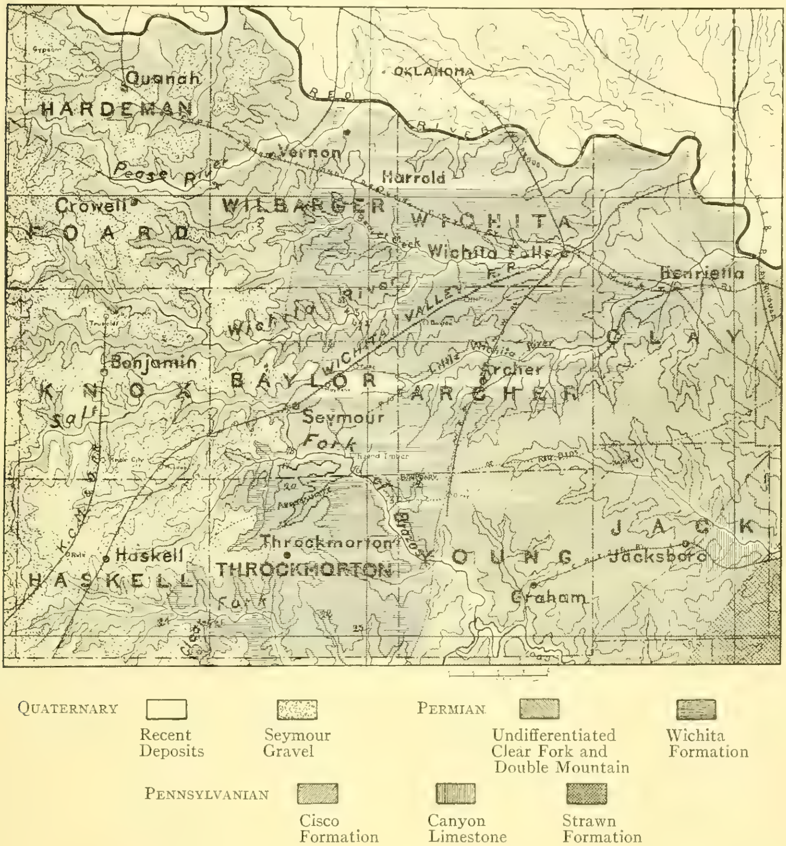
STRATIGRAPHY OF THE REGION

The "Red Beds" area.—The area occupied by the "Red Beds" in northwestern Texas is bounded on the west by the eastern escarpment of the Llano Estacado, and extends eastward along the Red River to Montague County, where the formations pass from sight beneath the basal beds of the Cretaceous. From this point the eastern boundary of the "Red Beds" bears south and then westward, following approximately the lines between Jack and Clay, and Young and Archer counties as far west as the Salt Fork of the Brazos. From this point it bears southwestward to the south-

[1] Published by permission of the Director of the United States Geological Survey.

eastern corner of Haskell County, thence irregularly south until it meets the Cretaceous again in Concho County.

As thus outlined, the "Red Beds" occupy an area of irregular shape 80 to 100 miles in width in the southern portion, while at



the north they extend eastward fully twice that distance along the south side of Red River. If a line be drawn from a point on Red River near the mouth of Pease River southwestward through Seymour to the northeastern corner of Haskell County and thence southward, it will mark approximately the eastern boundary of a series of red clays and red sandy shales containing gypsum in varying amounts, to which the names Clear Fork and Double Mountain

were applied by Cummins in reports of the Texas Geological Survey. These are evidently the equivalents of the beds included by Gould[1] in the formations to which he applied the names Greer and Quartermaster. As these beds have no connection with the problem in hand, they may be dismissed from further consideration. It is to that portion of the "Red Beds" area adjoining the Red River and extending eastward from the line above indicated that most of the discussions concerning the Texas Permian apply. This is the type area of the Wichita formation of Texas. The western part of this area is characterized by the occurrence of beds of limestone and blue shale interbedded with red clays and sandstones, while the eastern part is notable for the entire absence of limestones and the very limited development of blue shale and clay. If a line be drawn from a point where the Salt Fork of the Brazos crosses the boundary between Throckmorton and Young counties, a little east of north to Red River, it will mark approximately the boundary between the areas thus lithologically distinguished. According to Cummins' earlier writings[2] most of the rocks of this western area were assigned to the Clear Fork formation, while the strata occurring toward the east constitute his original Wichita division. Many of the fossils on which his conclusions regarding the Permian age of the beds were based, however, appear to have come from the basal portion of the limestone series in eastern Baylor County.

In the earlier reports the Wichita formation is described as having no surface development south of the point where the "Red Beds" boundary meets the South Fork of the Brazos River in the northeastern corner of Throckmorton County. From that point southward the Clear Fork formation is said to rest directly upon the "Albany," considered to be the highest division of the "Coal Measures" in that region. This peculiar relation of the Wichita formation was conceived to be due to overlap, and hence it was believed that an unconformity marked the relations of these beds to the "Coal Measures." In a later paper,[3] read before the Texas

[1] Charles N. Gould, *Water-Supply and Irrigation Paper No. 191* (1907), 14–19.

[2] *Geological Survey of Texas*, II (1890), 401. See map facing p. 552.

[3] W. C. Cummins, *Transactions of the Texas Academy of Science* (1897), II, 93–97.

Academy of Science, Cummins announced the discovery of evidence showing that the limestones of eastern Baylor County are the same as those of the "Albany." In this paper the beds of Baylor County are said to constitute the upper part of the Wichita. Owing to the discontinuance of the Texas Survey the report on this area prepared for the *Fifth Annual Report* has not appeared.

Rocks of the Wichita area.—East of Baylor County the rocks consist for the most part of red concretionary clays, red sandstones and sandy shales with occasional beds of blue shales, and bluish to grayish-white sandstones. Limestones are conspicuously absent. Occasional impure nodular layers occur, however, which contain considerable calcareous matter, but these do not constitute strata of limestone. The sandstones are usually soft and distinctly cross-bedded. In some places they are shaly, in others massive. Some layers are streaked and specked with grains of black iron oxide, while others contain nodular masses and concretions of iron ore.

The clays are mostly deep red or red mottled with bluish-white and drab colors. The red clays contain an abundance of nodular concretions of irregular shape varying in size from that of a pea to masses 4 or 5 inches in diameter. They consist of clay, iron, and lime, and at times are hollow or with the interior filled with calcareous clay or lime carbonate. In some cases they are flattened and stand in vertical position in the clays, suggesting their origin through the filling of fissures.

Occasionally a bed is met with consisting of rounded lumps of hardened clay cemented together by ferruginous matter, representing what Cummins called "a peculiar conglomerate." This formation is believed to have had its origin in the breaking-up of a bed of clay by running water or wave action.

In places the bluish clays are copper bearing. Efforts to mine these deposits, however, have not been profitable. The ore occurs in the form of small nodules in the clays and also as a replacement of wood.[1]

In the sandstones occasional traces of plants occur, and sometimes remains capable of identification are found. White reports *Taeniopteris* from the sandstones near Fulda. The stratification

[1] J. F. Cummins, *First Annual Report, Geological Survey* (Texas, 1889), 188–96.

of the beds is very irregular. The sandstones, shales, and clays grade into each other both vertically and horizontally. Moreover there is a monotonous similarity in the sandstones and shales respectively throughout the area, which, taken in connection with the absence of any persistent easily recognizable stratum, renders the stratigraphic correlation of the beds, except within very narrow limits, practically impossible.

In eastern Clay and Montague counties, the beds, considered Cisco, show a greater development of sandstones some of which are conglomeratic. In the western part of the area, however, no true conglomerates were observed.

As to the thickness of the Wichita, no definite statement can be made. Certain of the beds may be traced for a limited distance sufficient to indicate a general westward dipping of the strata. Cummins estimates it to be 35 feet per mile, which is probably too high. The width of the outcrop in an east-west direction is about 50 miles, which, assuming a regular inclination of 25 feet per mile, would give a thickness of 1,250 feet for the beds outcropping in this portion of the field. How much of this should be referred to the Cisco is conjectural, but probably not less than half. A well put down for oil at Electra, which is located near the top of the formation, passes through 1,790 feet of red clays with some sandstone and red sandy shales. At Petrolia, which is near the middle of the outcrop, the oil wells are for the most part about 400 feet deep, chiefly in red clays and shales. Drilling has extended to a depth of 800 feet in some instances and indicates an increase in the proportion of blue shales below, but no reliable record could be obtained of the lower formations passed through.

At Archer City a well 737 feet deep shows red clays and reddish sandstones predominating to a depth of 670 feet. Below this the drill revealed similar deposits but in diminished proportion, as compared with the light-colored sands and bluish clays. Since the upper beds of the Cisco in this region are prevailingly red, however, no reliable conclusion can be drawn from well records as to the plane of division between the formations.

In the bluffs of the Wichita River in the northwestern corner of Archer County some beds of limestones aggregating 4 feet in

thickness appear at the top of the escarpment on the west side of Horseshoe Lake, and outcrops of these appear at intervals along the boundary of Archer and Baylor counties. This limestone is earthy, very hard, dark blue where fresh, and weathers to dark brown or black. It is underlain by 4 feet of blue clay. The remainder of the section to the base of the hill, about 100 feet, consists of red concretion-bearing clays with a limited development of red and white shaly sandstone. From this point westward the stratification becomes more regular, consisting of the blue shales alternating with the red, the red being predominant, with an occasional bed of dark earthy limestone containing usually an abundance of poorly preserved fossils.

At the Bar-X ranch on the Wichita River in the northeast corner of Baylor County near the Old Military Crossing, several ledges of hard limestone appear in the river bluffs separated by varying thicknesses of blue shale, alternating with red clay. The beds dip to the westward at inclinations estimated at 20 to 30 feet per mile. Proceeding up the river from this point, limestones appear at intervals in increasing development, the best outcrops occurring about 2 miles east of where the Seymour-Vernon road crosses the river. Here an escarpment 90 feet in height has the lower two-thirds composed of red and blue shales alternating with beds of limestone. The middle of the section consists of red and concretionary clays and sandstones. Some of the ledges of limestone are massive, but others are thin-bedded and shaly, and separated by varying thicknesses of bluish clay. Locally the thin-bedded limestones and their included shale grade horizontally into more massively bedded limestones. Fossils are not plentiful in this locality. The same beds are exposed again northward in the banks of Beaver Creek. At Seymour the limestones are well exposed in the banks of the river where they are quarried to some extent and furnish a stone that is well adapted to ordinary uses. The beds are here transected by the Salt Fork of the Brazos River, which flows in a relatively narrow valley between steep bluffs 200 feet high, made up of interbedded red and blue clays, and limestones.

The limestones of Baylor County area are generally fossil-

iferous. Owing to the hardness of the rock, however, good specimens are difficult to obtain. Toward the south there is an increase in the development of blue shale and limestone, while the red clays and sand show a corresponding diminution. In a recent paper[1] Case has endeavored to correlate certain of the sandstones occurring throughout the area, one of which he calls Fulda, from a little station by that name in eastern Baylor County. With this sandstone he correlates others which outcrop as far east as Wichita Falls, a distance of 37 miles. With this conclusion the writer is not in accord. In the first place, the sandstones at Fulda are underlain by some thin limestones which outcrop toward the northeast in the northwestern part of Archer County. It is quite apparent that the sandstones in eastern Archer and Wichita counties represent horizons below these limestone beds. Assuming the general westward dip of the strata to be no more than 20 to 25 feet per mile, there must be a descent of not less than 650 to 800 feet to which must be added the rise of the plateau surface which is about 200 feet, making a total of 850 to 1,000 feet between the horizon represented at Wichita Falls and that at Fulda and rendering untenable the correlations suggested.

Albany area.—The eastern boundary of the Clear Fork and Double Mountain formation in eastern Jones County is marked approximately by the Clear Fork River. The region to the east of this point to the limits of the Cretaceous in western Parker and Wise counties, a distance of over 100 miles, known as the Brazos Coal Field, is occupied by rocks of Carboniferous age. These beds, which have a thickness of nearly 7,000 feet, present lithological, stratigraphic, and faunal characteristics, which permit their separation into four well-marked divisions, known as the Strawn, Canyon, Cisco, and "Albany" divisions.[2] Southward in the Colorado Coal Field the equivalent rocks were first studied by Tarr,[3] who

[1] E. C. Case, *Bulletin of the American Museum of Natural History*, XXIII (1907), 659–664.

[2] These names appear first in the *First Annual Report of the Geological Survey of Texas* in the State Geologist's "Report of Progress," pp. lxv–lxvii. Hill, however, credits them to Cummins (*Twenty-first Annual Report, U.S. Geological Survey*, Part VII, 97).

[3] R. S. Tarr, *First Annual Report of the Geological Survey of Texas* (1889), 201–16.

subdivided them into five divisions as follows: Richland, Milburn, Brownwood, Waldrip, and Coleman. Later the Milburn was included in the Brownwood.[1] The relations of these rocks as now recognized are as follows:[2]

Colorado Field (Tarr)		Brazos Field (Cummins)	Thicknesses in Feet
Coleman		"Albany"	1,200
Waldrip		Cisco	800
Brownwood Milburn	Brownwood	Canyon	800
Richland		Strawn	4,100

The beds dip to the west at a low inclination estimated by Cummins to be 30 feet per mile for the "Albany" and 75 for the Canyon.

Limestones constitute the dominant characteristics of the "Albany" and Canyon formations, while sandy shales and sandstones, with some conglomerates, make up the larger part of the Strawn and Cisco formations. It is with the two uppermost of these, the "Albany" and Cisco, that the "Red Beds" problem is concerned.

The "Albany."—The "Albany," named from the county seat of Shackelford County, consists of blue, gray, and yellowish limestones, alternating with beds of blue and dark-gray shales. The upper 500 feet are characterized by massive beds of hard blue limestone, with partings of blue shale, while the lower portion shows a greater development of shale, the limestone being for the most part thin-bedded and shaly. The heavy ledges of limestone appear at the surface in a succession of terraces which extend in sinuous curves from north to south. Sandstones and conglomerates are almost entirely lacking. The formation contains an abundant marine fauna, which, taken in connection with the notable development of limestones, indicates deep seas and quiet conditions of deposition. Above, the formation grades rather abruptly into red gypsiferous clays and red sandy shales and sandstones. The base of

[1] R. T. Hill, *Twenty-first Annual Report of the U.S. Geological Survey*, Part VII (1899, 1900), 98.

[2] The thicknesses cited are those given by Drake, "Report of the Colorado Coal Field of Texas," *Fourth Annual Report, Texas Geological Survey* (1892), 371–446.

the formation is placed just below the main limestone and the blue shale series, the line marking the boundary with the Cisco coinciding approximately with the east line of Shackelford County.

The Cisco.—Below the "Albany," and outcropping to the east of that formation, is the Cisco, which is composed of sandstones and shales, with some conglomerates and two or three beds of coal. Occasional beds of limestones occur in the lower part of the formation and again near the top. Coal outcrops along the Salt Fork of the Brazos River west of Graham in Young County, and elsewhere to the northeast and southwest. Some of the beds of coal are associated with limestones, in one case a thickness of two or three feet of limestone resting directly upon a bed of coal. The conglomerates consist of sub-angular fragments of flinty blue limestone and chert cemented together by a ferruginous sand. Nodules and hollow concretions of limonitic iron ore are common. These conglomerates have been recognized at two different horizons and in widely separated localities. Their exact relations, however, have not been clearly defined. In Stevens County the clays are mostly blue and yellow. Limestones appear at intervals, but these thin out northward, while the clays show a corresponding increase in development.

Relation of the "Albany" to the Wichita.—When traced northward, the limestones of both the "Albany" and Cisco formations diminish in thickness, while there is a corresponding increase in the intervening beds of shale. In the case of the "Albany" the limestones show also a change, becoming more earthy and irregular in their texture, and some of the beds passing into gray indurated clays. The few limestones in the upper part of the Cisco formation disappear entirely in the northern part of Young County. Along with this change there is an increasing development of red clay, alternating with the blue. The massive beds of limestones constituting the upper part of the "Albany" along the Clear Fork in northwestern Shackelford County and in western Throckmorton County were traced northward as far as Beaver Creek in eastern Wilbarger County. They appear in more or less continuous exposures as far north as Seymour, north of which they are covered, but are again exposed, greatly diminished in thickness on Big

Wichita River and Beaver Creek in the line of their strike northward. Greater difficulty is encountered in the effort to trace the lower beds of the "Albany," owing to the greater proportions of clays and sands and the disturbed condition of sedimentation, both conditions becoming more pronounced as the beds are followed northward. Certain of the limestone beds, however, are persistent, although showing changes in their physical character, and by means of these the eastern boundary of the formation was ascertained with a fair degree of accuracy. At Fane Mountain, a low elevation in the southeastern corner of Throckmorton County, is an outcropping of limestone characterized by an abundance of *Myalina permiana*. These beds occur at intervals northward in eastern Throckmorton County, and at Spring Creek in the northwestern corner of Young County they outcrop in the bank of the river about a mile from the post-office. Here the beds show locally a gradation into sandstone suggesting near-shore conditions of sedimentation. On Godwin's Creek, in the western part of Archer County, the diminished representatives of these, or possibly somewhat higher, beds appear, as also farther north on the Big Wichita River. The limestone which outcrops on the Big Wichita north of Fulda, referred to on p. 116, is evidently one of the lowermost beds. The most northerly appearance of presumably the equivalents of these beds was noted in the vicinity of Electra in the western part of Wichita County, where occasional plates of limestone appear over the surface apparently as a result of the weathering out of lenses of limestone in the clays. In the case of the Cisco formation the changes which these undergo toward the North have not had careful study. The limestone, however, appears to thin out entirely in the northern part of Young County, there being no representatives of these formations in the "Red Beds" area except it be the impure, calcareous nodular beds described above.

Nowhere in the southern area so far as observed are there any indications of unconformity. Notwithstanding the lithological and faunal characteristics which distinguish the "Albany," these beds appear perfectly conformable with the Cisco below and the Clear Fork above, nor is there within the formation any indication of stratigraphic discordance. The change in the lithological character

of the beds toward the north is evidently the result of differences in the conditions of sedimentation. The character of this part of the formation suggests very strongly its origin on a coastal plain, or river delta, to the south and west of which lay the sea in which were deposited the marine "Albany" sediments. The interrelations of the two kinds of sediments suggest oscillation of the shoreline upon a relatively wide coastal plain. These changes may be explained as the result of oscillation of the land surface or, possibly better, by the slow but intermittent sinking of the coastal region.

As suggested by Case,[1] Beede,[2] and others, the materials of the "Red Beds" were evidently derived from a land mass on the north, of which the Wichita and Arbuckle mountains are the remnants. The following quotation from Beede's paper is especially pertinent:

> The Arbuckle and Wichita mountains are probably the source of much of the red sediment in which they are partially buried, and the former mountains are directly responsible for the eastern extension of these beds in central Oklahoma. The extent to which the lighter colored sediments of Kansas and Texas are replaced by red sediments in Oklahoma and near it represents in a rough way the limits of the influence of these mountains on the deposits of the time by the spread of their sediments. By the time the deposition of the light colored sediments had ceased the conditions had become such that nearly all the sediments derived from the land surrounding the basin were red.

FAUNAL RELATIONS

In the course of the field work collections of fossils were made at many localities, chiefly in the region occupied by the "Albany" beds. At the close of this paper is given a list of the invertebrate fossils obtained from the Albany and Wichita areas. The list includes the collection made by the author, and those made several years since by Mr. E. O. Ulrich. The localities are indicated on the map by corresponding numbers. These remains indicate, according to Dr. Girty, a marked identity in the invertebrate faunas of the Albany and Wichita areas. In the collections several different faunas can be discriminated. One of these has the brachiopod

[1] E. C. Case, *Bulletin of the American Museum of Natural History*, XXIII (1907), 659–64.

[2] J. W. Beede, *Journal of Geology*, XVII (1909), 714.

element fairly well represented, *Derbya cymbula* being generally present, and the pelecypod *Myalina deltoidea* rather abundant. Another contrasting fauna has, as a rule, brachiopods absent or greatly diminished, but is plentifully supplied with large nautiloids. The faunas appear to have been contemporaneous, both occurring throughout the formation, but in different localities. The nautiloid facies, however, is more prominent in the upper series of beds.

The invertebrate remains of this region were studied by C. A. White,[1] who considered them to be Permian. A map on which the localities were shown was prepared for the *Fifth Annual Report* of the Texas Geological Survey, but never published.[2]

The collections of vertebrates, which in past years have attracted so much attention, were made in the adjoining portions of Baylor and Archer counties. Cope, who first studied them, considered them to be of Permian age. A description of the localities where these remains were discovered has only recently appeared in print.[3] From this description, which is not accompanied by a map, it appears that no fossils were obtained east of the middle of Archer County. In late years interest in the vertebrate remains of the Wichita formation has been renewed and much new material has been obtained, more particularly through the labors of Williston and Case. The results of their investigations have appeared in various papers.

The plant remains from this region have been studied by Fontaine and White[4] and by David White. The last named spent several days in the field in 1909 and collected considerable material from two near-by localities, one, two and one-half miles south of Fulda, and the other four miles southeast of that place. As provisionally identified this material is as follows:[5]

[1] C. A. White, *U.S. Geological Survey Bulletin 77* (1891).

[2] *Transactions of the Texas Academy of Science* (1897), 95.

[3] W. C. Cummins, *Journal of Geology*, XVI (1908), 737–45.

[4] I. C. White, *Bulletin of the Geological Society of America*, III (1892), 217–18. Study based on identifications by W. N. Fontaine.

[5] No. 1: Cassil Hollow, two and one-half miles south of Fulda, Texas. No. 2: Breaks of the Little Wichita, one-half mile south of the river, and four miles southeast of Fulda, Tex. The beds are just over the bone-bearing limestone. The species in bold-faced type are characteristic of the Permian.

Locality No. 1

Pecopteris arborescens
Pecopteris hemitelioides
Pecopteris densifolia ?
Pecopteris grandifolia
Pecopteris mertensioides ?
Gigantopteris sp. (cf. nicotianifolia)
Neuropteris (cf. lindahli)
Aphlebia sp.
Taeniopteris multinervis
Annularia spicata
Sphenophyllum ? sp.
Sigillariostrobus hastatus
Walchia schneideri ?
Gomphostrobus bifidus
Cardiocarpon n. sp.
Carpolithes sp.
Pelecypods
Estheria and fish scales

Locality No. 2

Pecopteris hemitelioides
Pecopteris grandifolia
Pecopteris candolleana
Pecopteris tenuinervis
Diplothmema ? sp.
Odontopteris fischeri ?
Odontopteris neuropteroides
Neuropteris cordata
Taeniopteris coriacea ?
Taeniopteris abnormis
Taeniopteris n. sp.
Sphenophyllum obovatum
Sigillaria sp. (leaf)
Gomphostrobus ? sp.
Cordaites principalis
Poacordaites cf. tenuifolius
Walchia piniformis
Aspidiopsis sp.
Araucarites n. sp.
Cardiocarpon n. sp.
Insect wings
Estheria
Anthracosia
Ostracods and fish scales

CORRELATIONS

That the limestone series of Baylor County is the equivalent of the "Albany" formation of the southern area is fully established by both the stratigraphic and the faunal evidence. The beds in the northern area, which include the limestones, shales, and sandstones of Baylor County and the sandstones and shales of Archer and Wichita counties, constitute the Wichita formation. Our investigations therefore fully support the conclusions of Cummins[1] and Adams[2] as to the equivalency of the "Albany" and Wichita formations.[3]

[1] W. C. Cummins, *Transactions of the Texas Academy of Science*, II (1897), 93–97.

[2] George I. Adams, *Bulletin of the Geological Society of America*, XIV (1903), 191–200.

[3] Along with the limestones of northeastern Baylor County which Cummins has designated as the top of the Wichita the writer would include the overlying beds of shale and limestone mapped by him as Clear Fork, which outcrop in the banks of the Big Wichita about a mile east of the Seymour-Vernon road and northward on Beaver Creek.

Gould[1] correlated the Clear Fork with the Enid, Blaine, and Woodward formations of Oklahoma. In making this correlation, he evidently followed Cummins' earlier writings, in which the beds of Baylor County were considered to be Clear Fork. Williston states[2] that the Enid formation of Gould is identical with the beds of Baylor County.

NOMENCLATURE

In the paper cited, Adams has contended that the terms Wichita, Clear Fork, and Double Mountain should be discarded as having no stratigraphical significance. In his latest papers, Cummins recommends the abandonment of the term Albany and the use of the term Wichita for the formation. In view of the conflicting statements that have been made as to the relations of the beds called Wichita we were at first inclined to agree with the first-named writer in recommending the abandonment of the term Wichita. Further consideration, however, leads us to conclude that with a revised definition it will be best to retain the name Wichita for the formation overlying the Cisco, which it is now generally agreed should be regarded as of lower Permian age, and to abandon the name "Albany."

The series of red clays and sandstones with their included gypsum deposits which in Texas overlie the Wichita formation and to which the names Clear Fork and Double Mountain have been given have not as yet received much study. With the limited amount of knowledge available the attempt to subdivide these beds seems to the author unwarranted, and they are, therefore, here mapped as "undifferentiated Clear Fork and Double Mountain."

CLASSIFICATIONS

The Permian age of the beds to which the name of Wichita was originally applied has been accepted quite generally, though there are not wanting those who regard the evidence as unsatisfactory. It was based chiefly upon the vertebrate and plant remains. In the southward, or "Albany," area the beds are wholly marine and

[1] C. N. Gould, *Water-Supply Paper No. 154*, U.S. Geological Survey (1906), 17.

[2] Letter to the author dated August 6, 1909.

destitute of both plants and vertebrates, though abounding in the remains of invertebrates. The Pennsylvanian aspect of this fauna has strongly impressed some investigators, including the author of this paper, and doubt was entertained as to whether the plane of separation between the Pennsylvanian and the Permian should be drawn at the base or at the top of the formation. The studies of David White, Beede, and others have contributed much in recent years to a knowledge of the Permian in American and in the main support the view of the Permian age of the Wichita formation. In a recent paper Beede[1] has ably discussed the Permian of Kansas, with which he correlates the "Red Beds" of Texas. Cummins correlates the beds of eastern Baylor County which he regards as the top of the Wichita formation with the Fort Riley limestone of the Chase group of Kansas. "It is quite certain that the Fort Riley horizon is the same as the Wichita of Texas and is at the very top of the division."[2] The top boundary of the Wichita formation was drawn by Cummins[3] at the top of a stratum of red clay overlain by thin beds of limestone and blue shales at a point on the Big Wichita four miles west of the east boundary of Baylor County. However, as we have shown, beds which are undoubtedly the same as those which appear at Seymour and southward in Throckmorton County appear in the banks of the Big Wichita River some eight to ten miles west of this point. The thickness of the strata included here, which overlie Cummins' topmost beds, and are here included with them in the Wichita formation, is estimated to be 250 to 300 feet. The whole limestone and shale series of Baylor County, thus included as the upper division of the Wichita formation, is provisionally placed at 450 to 500 feet, and consists, as shown elsewhere, of limestone beds of varying thicknesses separated by varying but usually great thicknesses of shale.

How much of this is to be correlated with the Fort Riley limestones can be determined only by more detailed stratigraphic and paleontologic studies. Cummins evidently intended to include

[1] J. N. Beede, *Journal of Geology,* XVII (1909), 710–29; *Kansas University Science Bulletin,* IV, No. 3 (1907).

[2] W. F. Cummins, *Transactions of the Texas Academy of Science,* II (1897), 98.

[3] *Second Annual Report, Texas Geological Survey* (1891), 402, 403; also *Fourth Annual Report* (1893), 224.

the lower beds only in his correlation. It may be that further studies will show that the overlying beds of the Winfield limestones of Kansas are represented here.

DISCUSSION BY GEORGE H. GIRTY

The equivalence in a general way of the fossiliferous late Carboniferous beds of Kansas and Texas has long been recognized and in both cases they have very generally been cited as Permian. Cummins,[1] partly on stratigraphic and partly on paleontologic evidence, reached the conclusion that the Fort Riley limestone of Kansas occupies a position at the top of the Wichita formation of Texas. The Fort Riley is the middle formation of the Chase group, the lowest group of the Kansas Permian, so that the bottom of the Wichita may well be as low as the base of the Permian of Kansas. This correlation of Cummins is probably the most precise and the best sustained of any, and it is also in accord with some recent paleobotanic evidence. Mr. White states in the present paper in discussing the fossil plants which he obtained from the Wichita formation that the latter is probably referable to the Chase group of Kansas.

Not until recently, it seems to me, has adequate evidence been adduced either for distinguishing the Permian of Kansas and that of Texas sharply from the underlying Pennsylvanian or for correlating them with the Permian of Europe. C. A. White found the Wichita fauna to have essentially a Pennsylvanian ("Coal Measures") facies, in which, however, certain characteristic Permian Ammonites occur. A similar conclusion seems to be demanded by the evidence of the present collections.

In all, 75 species have been discriminated in the Wichita collections which I have studied, the local distribution of which is shown in the table prepared by Mr. Gordon accompanying the present paper. The identifications naturally vary in precision and refinement. In many cases it has been possible to name only the genus to which a species belongs. This is sometimes due to the fact that the species is undescribed. In a few instances species have been cited by comparison with others, e.g., *Bellerophon aff. harrodi.*

[1] *Trans. Texas Acad. Sci.*, II (1897), 98.

If such citations are included as species identified, 48 species of the fauna are identified and 27 are unidentified. Of the 48 species identified, 37 are known to occur in the Pennsylvanian rocks of the Mississippi Valley. Most of them are cited by Dr. Beede in his table showing the Pennsylvanian faunas of Kansas. The large percentage of indeterminata introduces a considerable possibility of error in the inference that 75 per cent of the fauna of the Wichita formation consists of well-known Pennsylvanian types, but it is undoubtedly true that in the main this fauna has a Pennsylvanian facies. One or two new forms at present excluded from the identified species would somewhat decrease this percentage. On the other hand, of the 25 per cent which is not known to occur in the Pennsylvanian of the Mississippi Valley, relatively few species are characteristic of the Permian of that area; still fewer, if any, are characteristic of the Permian of Europe. Some of them occur in western faunas, probably contemporaneous with the eastern Pennsylvanian. *Bellerophon subpapillosus* is one of these. Twenty-five in a hundred, therefore, far overstates the percentage of characteristic Permian species. Such percentage, however, might be considerably increased by the inclusion of certain species known to occur in the Wichita formation but not represented in the Survey collections. I refer especially to the Ammonite forms described by C. A. White from the Military Crossing of the Wichita. These are by all means the most diagnostic Permian types of the fauna. How little characteristic of it they really are, however, is shown by the fact that later collections made at the same place fail to contain them, although a special search was made to secure additional representatives.

Mr. White finds that about 50 per cent of the Wichita flora consists of species characteristic of the Permian, while most of the remainder are known to occur in rocks regarded as of Permian age. If we omit the fauna of the Kansas Permian, to include which would be a sort of *circulus vitiosus*, no condition comparable to this has been demonstrated by the invertebrate fossils and, in so far as I have seen the evidence, no such condition exists. I am, therefore, accepting the Permian age of the Kansas and Texas beds, but at present strictly on the paleobotanic evidence.

If the upper part of the Carboniferous section of Texas is to be discriminated as Permian, the line of division, as indicated also by the paleobotanic evidence, would probably best be taken at the base of the Wichita.

An inspection of the faunas collected from the strata immediately concerned in this report shows a rather noteworthy change of facies between the Wichita and the Cisco—a change, however, which is more or less progressive and has its beginning in earlier beds. This shows itself rather in a limitation than in a change of fauna and in the prominence of certain groups more rare below. Thus the brachiopods, pelecypods, gasteropods, etc., are much less in evidence in the Wichita than in the Cisco, but, as already pointed out by C. A. White,[1] they are essentially the same as those of the normal Pennsylvanian fauna. In the Wichita, however, we have a remarkable development of the Cephalopoda, which in the earlier sediments are rare.

Just what significance faunal changes of this sort possess it is difficult to say. It seems to be a change comparable to that which is more strikingly illustrated when a thin calcareous sheet with a marine fauna occurs in the middle of a coal deposit. Here, of course, there is an absolute change from the animal life of the calcareous stratum to the plant life of the coal and roof shale, but in this case the significance is not ambiguous and it is clearly not stratigraphic.[2] So I think the faunal change marked by a substitution of one predominating animal type for another may often be more safely interpreted as environmental than as stratigraphic in its import. At the same time the stratigraphic significance may be present also, which would appear to be the case with the Wichita auna, as indicated by the fossil plants. Nevertheless, this change, as marking the evolution from one geologic period to another, would be more impressive if the molluscan and molluscoidean groups were continued into the Wichita and with a difference of facies such as is usually found when the faunas of other systems are contrasted.

[1] *U.S. Geol. Surv., Bull.* 77 (1891), 30–39.

[2] I mean of course that there is usually no time break and no appreciable change of fauna in the general region accompanying the phenomenon.

In connection with the correlation of the Wichita formation with the Permian of Europe, it may be well once again to consider the use and definition of the term Permian.

As is well known, Murchison correlated with the English "Millstone grit" a series of sandy beds which underlies the typical Russian Permian, and therefore this series, to which the name Arta beds or Artinskian was subsequently given, was distinctly excluded from the original or typical Permian. It has since been recognized that the Arta beds are not the equivalent of the "Millstone grit," and that the fossils which they contain show affinities with both the "Upper Carboniferous" below and the Permian above. The Artinskian therefore came to be called also "Permo-Carboniferous," and by many writers it is included with the other under the name Permian.

While the typical Permian is usually underlain by the sandstones of the Artinskian, over a considerable and well-defined area a heavy series of limestones and dolomites has been found to intervene. This apparently lenticular mass has been called the Kungur-stufe, and on paleontologic evidence has been by Tschernyschew united with the Artinsk and included under the term "Permo-Carboniferous," which, therefore, comprises two divisions, the Arta beds below and the Kungur beds above.

Now, the propriety of including the original Permian and "Permo-Carboniferous" in a single group is, of course, a question quite apart from the nomenclature which should be used, and it is a question with regard to which one who has not studied the rocks and fossils in the typical region can hardly render an authoritative opinion. There seems to be European authority both for excluding the "Permo-Carboniferous" from the Permian and for including it with it, the greater number of writers, it may be, adopting the latter course.

As for the plants, Mr. White states that "from the paleobotanical standpoint the Artinsk stage of Russia is clearly Permian."

My own knowledge of the facts is only that of the library, but I should judge that the faunal break was greater between the Gschelian and the "Permo-Carboniferous" than between the "Permo-Carboniferous" and the original Permian. That is, of the

very varied brachiopod fauna described by Tschernyschew from the Gschel but a small number of species appear to pass over into the Artinsk, and I infer that much the same is true of other groups. Both for this reason and because the Artinsk seems to introduce a new "cycle of deposition," I would be disposed to group the "Permo-Carboniferous" with the beds above rather than the beds below, not feeling, however, that my opinion on this point deserves much weight.

Now, while there may be diversity of opinion about grouping together the "Permo-Carboniferous" and Permian, all must agree that it is bad usage to employ the name Permian in two different senses, especially for the whole and at the same time for a part. Although the question is international as well as national, the proposition to remedy the present unfortunate condition would come with greater force and propriety from European writers. To me, personally, it is naturally a matter of indifference whether the term Permian is used for the series and a new name introduced for the beds above the "Permo-Carboniferous," or used for the beds above the "Permo-Carboniferous" and a new name introduced for the series.[1] The former alternative has in its favor the fact of perhaps greater usage; the latter, that it is the original and authoritative usage. I cannot believe that the unscientific procedure of employing the term in two senses will continue indefinitely, and consequently whatever we now do, short of the fundamental courses just named, must be more or less of a makeshift. It does not, perhaps, make much difference which method is adopted in this provisional manner, but as the main object is to be clear and exact, it has to me seemed the better plan to use Permian in the original and authentic sense.

It seems to me obvious that the Artinskian and Permian should be assembled under one division or separated into several, entirely as the sum of the evidence from all sources dictates. I have not the personal acquaintance with the beds, their faunas and floras, their field relations, etc., which would entitle me to an opinion of my own as to how they should be classified. It seems to be a moot

[1] Possibly some older name could be revived for the Permo-Carboniferous and Permian, such as Dyas, as suggested by David White.

point whether the Arta beds should be regarded as a separate division or included with the Permian, and it matters little for purposes of correlation whether an American writer follows one group of authorities rather than the other. Personally, I am quite willing to include them both in a single division of the time scale, and although believing that propriety would be better served by retaining Permian for only the upper division, I am willing to extend that term to cover the entire series because of the usage which it has received in this sense, but I am not willing, for reasons which must be obvious, to call the whole Permian and the upper part also Permian, and for the sake of precision I have been temporarily calling the upper beds Permian, the lower beds "Permo-Carboniferous," and the whole "Permo-Carboniferous" and Permian. If, in my Guadalupian report and elsewhere, I restricted the term Permian to the supra-Artinskian beds, it was done as a matter of procedure in nomenclature. I had no opinion of my own as to the classification of the beds to express or defend, although, if I had, excellent authority could be named in support of my position.

DISCUSSION BY DAVID WHITE

The plant material collected by myself from the breaks of the Little Wichita River near Fulda, Tex., is derived from two near-by localities, both near the middle of the Wichita formation. The fossil plants previously listed by Fontaine and White from two other localities, and recorded[1] by them as Permian, appear to represent a mixed flora, one of the localities being under suspicion of Pennsylvanian age. Neither of the latter two localities was visited by me on account of the lack of time; but on the basis of information received, I am disposed to believe that the stratigraphically lower beds at Antelope are probably Pennsylvanian.

The identifications given on p. 122 are provisional. Later it is hoped, when the material will have been increased both geographically and stratigraphically, a formal report covering the floras of the "Red Beds" will be prepared. The species printed bold-face in the lists on p. 122 are characteristic of the Permian. They point somewhat distinctly to the Rothliegende age of the beds.

[1] *Bull. Geol. Soc. Amer.*, III (1892), 217.

All the Old World species in the lists occur in the Permian of western Europe, and of the remaining species apparently every one which is not new is found in the Permian of Kansas. *Taeniopteris*, in simple fronds, is represented by several species characteristically lower Permian. Other types proper to the Permian are the *Odontopteris* form, the genus *Gomphostrobus*, *Annularia spicata*, the *Sphenophyllum* forms, one of which approaches *S. stoukenbergii*, and the scales provisionally referred to *Araucarites*, while the presence of *Walchia* assures a horizon as high as the highest "Coal Measures."

The presence of *Gigantopteris*, abundant at locality No. 2, is particularly notable since the genus is not definitely known except from the coal fields of central and southern China, where it occurs in beds associated with the coals overlying other terranes which, on the evidence of their contained invertebrates, have been referred by the French geologists to the lower Permian. The genus is certainly close to, if not actually identical with, a form described from several small fragments from the Permian of the Ural region.

In accordance with the paleobotanical standards of western Europe, I refer the plants of the Little Wichita in Texas to the lower Permian, the terranes being probably referable to the Chase group in Kansas. In this connection it should be observed, however, that the Artinskian flora of the Urals is essentially Permian, and that paleobotanists universally agree with the general usage of the geologists of western Europe in referring the Artinsk to the Permian.

DESCRIPTION OF LOCALITIES

NOTE.—The number at the left is the locality number as given at the head of the list and indicated on the map. The first numbers following the description of locality are the Survey permanent record numbers, the second the temporary or field numbers.

1. Bar-X Crossing, Big Wichita River, three miles north of Fulda Station, 5247 (Gi. 67).
2. Bluff of Wichita River, one mile west of Bar-X ranch house, 5243 (Ri. 29).
3. One mile east of Old Military Crossing, Wichita River, 7025*a*.
4. Two miles north of Wichita River, near Old Military Crossing, 7025*b*.

LOCALITY LIST OF INVERTEBRATE FOSSILS FROM THE WICHITA FORMATION, TEXAS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Allerisma terminale									×									×	×							
terminale var.																										×
Ambocoelia planiconvexa																			×							
Annelid n.g.n.sp.									×	×	×										×				×	
Aviculipecten aff. whitei														×											×	
sp.															×							×				
Aviculipinna nebraskensis																								×		
peracuta							×		×											×	×					×
sp																		×							×	
Astartella concentrica												×														
Bakewellia ? sp.							×																			
Bellerophon crassus			×			×			×									×	×						×	×
aff. harrodi												×														
sp.				×																						
Bucanopsis meekana													×													
Chonetes sp																		×								
Composita subtilita																			×			×				
Coloceras globulare								×	×		×							×	×							
Deltopecten occidentalis																								×		
Dentalium sp																×										
Derbya cymbula													×			×		×			×	×				×
sp							×					×														
Entomis sp									×																	
Estheria dawsoni							×																			
Euomphalus pernodosus																										×
catilloides											×															
sp							×																			
Euphemus subpapillosus									×																	
Fusulina sp																		×	×							
Fistulipora sp																			×							
Fenestella sp																										
Leperditia sp			×			×		×	×								×	×								
Lingula aff. tighti							×																			
aff. carbonaria								×																		
sp.														×												
Lophophyllum profundum																			×							

Loxonema (sev. sp.)													×													
Meekella striaticostata											×															
Murchisonia aff. terebra											×	×														
sp							×		×									×			×					
Myalina perattenuata											×															
deltoidea												×			×	×										
permiana	×	×		×	×			×		×	×							×				×	×	×	×	
Nalicopsis sp	×						×																	×		
Nautilus sp		×	×						×																	
Nucula aff. beyrichii							×																			
Orthoceras sp					×		×	×			×						×	×	×							
Pelecypoda indet																	×									
Petellostium montfortianum												×														
Phacoceras dumblei			×					×			×									×						
Phyllopora sp																×										
Plagioglypta aff. canna												×														
Pleurophorus calhouni											×										×			×		
subcuneatus				×	×		×	×	×	×			×					×								
sp											×								×							
Productus cora																										
semireticulatus																		×		×		×			×	×
Rhombopora lepidodendroides																×										
Schizodus compressus																										×
ulrichi																								×		
sp																										
Sedgewickia topekensis																										×
Septopora biserialis																×										
Sphaerodoma intercalaris											×															
sp												×														
Spirorbis sp			×															×							×	
Stenopora sp							×									×										
Strophostylus nanus											×															
peoriensis												×	×													
remex					×				×	×	×															
Tainoceras occidentale					×			×	×									×	×							
cavatum								×										×								
Temnocheilus aff. depressum	×	×					×											×								
aff. forbesianum					×			×			×							×								
Zygopleura aff. rugosa																		×								

5. Four to five miles northwest of Old Military Crossing, Wichita River, 7025, 7025*c*.

6. Near Old Military Crossing, Wichita River, 7025*d*.

7. Three miles northwest of Fulda Station, near No. 2, 7026.

8. Four miles northwest of Mabelle Station (section house), 7028.

9. Eight miles southeast of Seymour, 5998 Deep Creek.

10. Head of Godwin Creek in eastern Baylor County, 7031, 7031*a*.

11. Godwin Creek near county line on Seymour-Archer city road, 5242 (R1. 29).

12. One to two miles northeast of Spring Creek, Young County (R1. 30).

13. One mile west of Spring Creek, 7035 (G1. 12, G1. 14).

14. Five miles south of Spring Creek, in Butte, 5216 (G1. 11).

15. Seven miles south of Spring Creek, Young County, 5217 (G1. 15).

16. Rocky Ford, Salt Fork, southeast corner of Baylor County, 5218 (G1. 9).

17. Quarry bank of Salt Fork, Seymour, 5220 (G1. 7).

18. West bank of Salt Fork, eight miles south of Seymour, 5222 (G1. 35).

19. Nine and one-half miles south of Seymour, Miller's Creek, 5221, 5224 (G1. 34).

20. Buttes, near wagon road, half-way between Throckmorton and Seymour, 7036 (G1. 32).

21. Three miles north of Throckmorton, 5215, 5227 (G1. 30).

22. Five miles west of Woodson, Throckmorton County, 5219, 5223, 5223*a* (G1. 25, G1. 26, G1. 27).

23. Fane Mountain, three miles southwest of Murray P.O., 5226 (G1. 24).

24. Paint Creek, southeast corner of Haskell County, 5245 (R1. 32).

25. Clear Fork, near southeast corner of Haskell County, 5231, 5232, 5241 (B1. 6, B1. 7, B1. 8).

26. Round Mountain on the Clear Fork, near 25, 5237, 5237*a* (R1. 34).

NOTES ON THE OSTEOLOGY OF THE SKULL OF PARIOTICHUS

E. B. BRANSON
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In the summer of 1910 Dr. S. W. Williston asked the writer to study the Pariotichus skulls in Walker Geological Museum of the University of Chicago to see if they would throw any light on some of the undecided points concerning the osteology of that genus. The material was fragmentary with the exception of one remarkable specimen of *Pariotichus laticeps* Williston, a skull of *Pariotichus aguti* Cope ?, and the base of a skull of an unidentified species. Some of the undecided questions were: Are squamosal and prosquamosal both present? Is there a distinct quadratojugal? What are the homologies of the tabulare, if such a bone is present? What are the homologies of the so-called epiotics, quadratojugals of Case? Is a presphenoid present? and What is the arrangement of the bones in the base of the skull?

The writer's thanks are due Dr. Williston for the use of the specimens and for discussions during the investigation.

In a paper published in 1878[1] Cope gave the name *Pariotichus brachyops* to an imperfect skull from the Permian of Texas, and later in the same paper described a more perfect skull as *Ectocynodon ordinatus*. As he supposed that the former had the roof of the skull unsculptured he referred the specimens to different genera. In 1882 he described *Ectocynodon aguti*[2] and in 1888 *Ectocynodon incisivus*.[3] In 1896 he referred all of the Ectocynodonts to Pariotichus and named two more species, *P. aduncus*[4] and *P. isolomus*.[5] In the paper where he named the latter he described

[1] *Proc. Am. Philos. Soc.*, XVII, 508.

[2] *Ibid.*, XX, 290.

[3] *Trans. Am. Philos. Soc.*, XVI, 290.

[4] *Proc. Am. Philos. Soc.*, XXXV, 135.

[5] *Ibid.*, XXXIV, 145.

Captorhinus angusticeps, which has recently been referred to Pariotichus by Broom.[1] In 1909 Williston described and figured *Pariotichus laticeps*.[2]

Roof of skull.—No separation of the squamosal into two bones was observed in either Pariotichus or the closely related genus Labidosaurus. Williston first called attention to this in Labidosaurus[3] and Broom shows no separation in his figures of Pariotichus.[4]

A quadratojugal is present in its normal position in the temporal region and this bone is also present in Labidosaurus. Its distinctness is not apparent in the type specimen of *Pariotichus laticeps* Williston, and was first noted in a specimen of Labidosaurus recently acquired by Walker Geological Museum, and corroborated by examination of other specimens. Dr. Case calls an element in the base of the skull the quadratojugal, but it seems to be a part of the squamosal. This part of the squamosal is indicated by the numeral "2" in Fig. 3. In a specimen of Labidosaurus figured by Williston, this part of the bone seems to be separate, but in all other specimens examined there is no evidence of separation. Dr. Williston worked over all of the skulls of Pariotichus and Labidosaurus in the Walker Geological Museum to see if we agreed on this point and we are now in accord in saying that this is probably not a separate element.

In 1883 in describing *Pariotichus megalops*, since referred to Isodectes, Cope said: "At the extreme posterior angle is a very small element in contact with the supraoccipital which may be the true intercalare."[5] In 1896 he figured this bone in *Pariotichus aguti* Cope,[6] and Case[7] and Broom[8] figure it in *Pariotichus angusticeps* Cope. It is present in the form figured in this paper; and in one or two other specimens of Pariotichus examined by the writer

[1] *Bull. Am. Mus. Nat. Hist.*, XXVIII, 218.

[2] *Biol. Bull.*, XVII, 241–55.

[3] *Am. Jour. Anat.*, X (1910), 74.

[4] *Bull. Am. Mus. Nat. Hist.*, XXVIII, 218.

[5] *Proc. Am. Philos. Soc.*, XX, 630.

[6] *Am. Naturalist*, XXX, Pl. VII.

[7] *Bull. Am. Mus. Nat. Hist.*, XXVIII, 194.

[8] *Ibid.*, XXVIII, 218.

it is distinctly separated from the parietal, but there is no indication of it in Labidosaurus. Cope also applied the name tabulare to the element and recently Broom has suggested the name post-temporal. There seems to be no valid objection to tabulare and it has the advantage of priority over Broom's name.

All writers seem to be agreed about the rest of the bones in the roof of the shull.

Base of skull.—The bases of several skulls examined during the investigation were fairly well preserved and the one from which Fig. 3 was made is almost perfect. This shows the post-parietals in the same position as figured by Williston in Labidosaurus[1] and by Case in Edaphosaurus[2] and Pariotichus. (Case calls them epiotics in Edaphosaurus.)

The exoccipitals are large and articulate with the squamosals after passing in front of the inturned edge of the latter, the quadratojugals of Case. The stapes, tympanic of Broom, articulates at its distal end with the lower inner end of the quadrate. In the drawing it is not shown distinctly separated from the exoccipital, the sutures not having been determined. The separation in this form is probably as shown by Williston in Labidosaurus.

The position of the quadrate is almost vertical with a broad bladelike process above and a heavy expanded portion below. The bladelike portion projects forward almost parallel with the median line of the skull, and the posterior end of the pterygoid rests against it. Its upper end comes in contact with the squamosal and the outer side of the base touches the quadratojugal.

Floor of skull.—The pterygoids extend from near the posterior end of the skull almost to the anterior end. They meet in the median line and are not separated by the basisphenoid as shown by Broom in *Pariotichus angusticeps* Cope.[3] The sutures between the long slender palatines and the pterygoids were made out in one specimen from the anterior end to near the posterior end, as shown by solid lines in the drawing. There are strong indications of a transverse as shown by broken lines in Fig. 4, but the evidence

[1] *Amer. Jour. Anat.*, X, Pl. III, Fig. 4.

[2] *Revision of the Pelycosauria of North America*, 1907, p. 153.

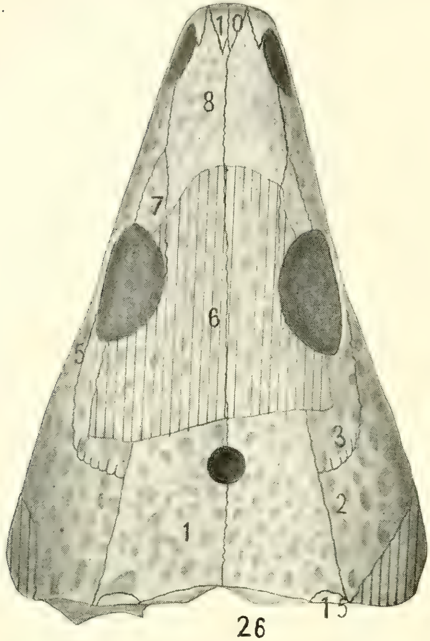
[3] *Bull. Am. Mus. Nat. Hist.*, XXVIII (1910), 218.

is not entirely convincing. The presphenoid is perfectly preserved in one specimen in Walker Geological Museum but is lost in all others examined. It is slender and extends about half the distance from the basisphenoid to the anterior end of the skull. The sutures between the vomers and palatines are not evident in any of the specimens studied.

In the specimen shown in Figs. 1 and 2, which is probably *Pariotichus aguti* Cope, though it has only two teeth on the premaxillaries, the teeth on the maxillae are in one row to behind the fifth where a second row begins inside the first, and behind this two other rather indistinctly defined rows appear. Nearly all of the teeth are subcircular in cross-section near the base, but some of the posterior ones are more or less compressed laterally.

The distinction between Pariotichus and Labidosaurus made by Cope, that the latter had the teeth of the maxillae in one row, breaks down in the Walker Geological Museum specimens. In two specimens examined during the present investigation a second row of teeth is evident and in other specimens the preservation is not such as to show whether there is more than one row.

Mandible.—The dentary makes up the outer part of the anterior half of the mandible. Just behind the dentary there is a short coronoid which occupies about one-third of the width of the jaw and sends upward a very large coronoid process almost equal in width to the rest of the mandible. Behind the coronoid the angular makes up most of the outer part of the posterior half of the jaw, and also sends forward a slender process between the dentary and the splenial, which reaches almost to the tip of the mandible. Above the angular and separated from it by a suture that runs diagonally across the jaw and passes to the posterior inferior corner, there seems to be a surangular. The splenial is not well preserved in any specimen observed and all that can be determined is that it is a broad flat bone on the inside of the jaw. The articular is imperfect in all of the specimens, but in a perfect specimen of a closely allied form, found completely separated from the other bones of the jaw, it is heavy at the posterior end and sends a long slender process forward.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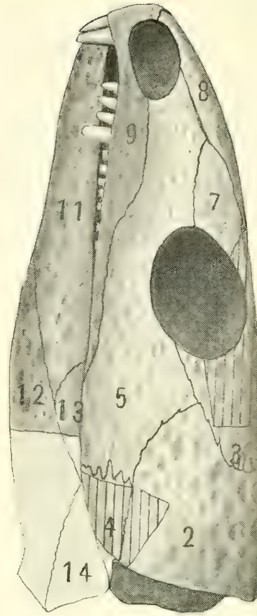
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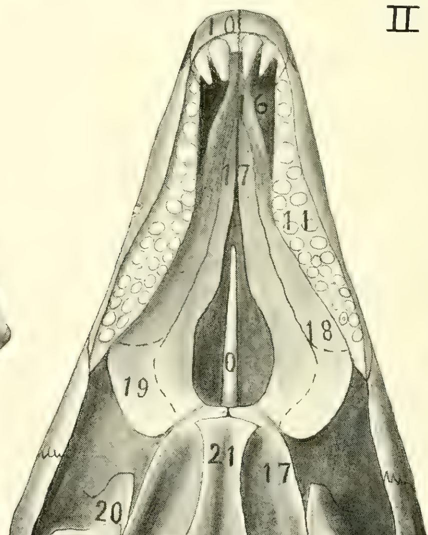
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IV

EXPLANATION OF PLATE

(The figures on this plate are natural size)

FIG. 1.—Top view of skull of *Pariotichus aguti* Cope.

FIG. 2.—Lateral view of skull of *Pariotichus aguti* Cope.

FIG. 3.—Base of skull of Pariotichus, species unidentified.

FIG. 4.—Floor of skull of Pariotichus restored from three specimens.

1, parietal; 2, squamosal; 3, postorbital; 4, quadratojugal; 5, jugal; 6, frontal; 7, prefrontal; 8, nasal; 9, maxilla; 10, premaxillae; 11, dentary; 12, angular; 13, coronoid; 14, surangular; 15, tabulare; 16, vomer; 17, pterygoids; 18, palatines; 19, transverse; 20, quadrate; 21, basisphenoid; 22, basioccipital; 23, stapes; 24, exoccipital; 25, supraoccipital; 26, postparietal. (As the surface sculpture was not well preserved in any of the specimens no attempt was made to reproduce it exactly in the drawings.) Lined areas are restored.

HIGH TERRACES AND ABANDONED VALLEYS IN WESTERN PENNSYLVANIA[1]

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U.S. Geological Survey, Washington, D.C.

The terraces with which this paper has to do are the well-known gravel-covered rock shelves found along the Allegheny, Monongahela, and other large streams of western Pennsylvania, about 200 feet above present stream channels. The abandoned parts of valleys are closely associated with the terraces, being found at the same elevation, and in many places the two are connected. Fig. 1 shows the principal areas of high terrace. The region includes all the Ohio River basin above New Martinsville, where there was formerly a divide. There are, however, terraces and abandoned parts of valleys of the same age on the Kanawha, Guyandot, Big Sandy, Kentucky, and other streams.

The impressiveness of these features is attested by the long list of names of eminent men who have studied and described parts of them. This list includes Stevenson, Leslie, Jilson, Chance, Wright, Chamberlin, Gilbert, I. C. White, Tight, Campbell, E. H. Williams, Leverett, and others.

Some of the earliest workers believed that the terraces were due to a submergence and marine erosion. Stevenson in 1879 (*Proc. Am. Phil. Soc.*, XVIII, 289–316) called attention to benches along the valley of the Monongahela and its tributaries. He divided them into a higher series of twenty benches, and a lower one of five. The higher series he attributed to marine action. They are probably entirely above those under discussion, and later work on them has shown that they are obscure and are probably due to hard layers of rock. The lower series of Stevenson seems to include those under discussion, and he refers them to stream action, without going into details of development.

[1] Published by permission of the Director of the United States Geological Survey, Washington, D.C.

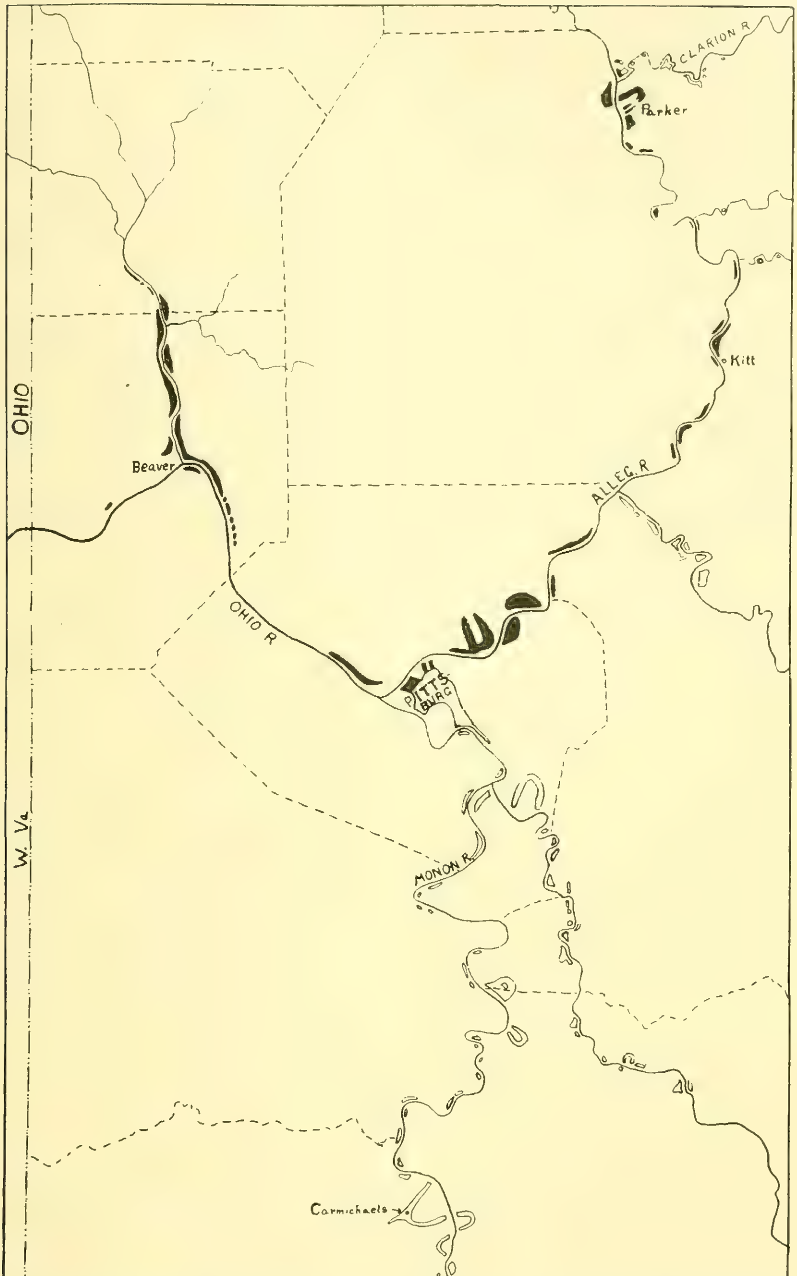

FIG. 1.—Principal areas of high terrace. Black areas have glacial gravel; those in outline have local gravel only.

In 1883 Professor G. F. Wright presented evidence of a large ice dam at Cincinnati, and shortly thereafter Professor I. C. White, in a paper before the American Association for the Advancement of Science, referred the terrace deposits of the Monongahela to that dam.

Chamberlin, in 1890 (*Bull. U.S. Geol. Surv. No. 58*, 13–38), showed that the upper series described by Stevenson could not be ascribed to the ice dam, because of their great range in altitude. He also pointed out certain characters of Stevenson's lower series which indicated that they were of fluviatile, not lacustrine, origin. These characters were: (1) the terraces slope with the present streams; (2) the material capping the terraces is distinctly fluvial; (3) they are rock platforms; (4) the form and distribution of the terraces is of fluvial, not lacustrine, order; (5) the abandoned channels must have been of stream origin.

In 1896 Professor White expressed himself (*Am. Geol.*, XVIII, December, 1896, 368–79) as still convinced that the glacial lake, Monongahela, did exist and was responsible for the terrace deposits, but that the ice dam was probably not at Cincinnati, but in the vicinity of Beaver, Pa.

In the Masontown-Uniontown folio, published in 1902, M. R. Campbell advances the theory that the deposits and abandoned channels are due to local ice dams which formed in Kansan time. He points out the fact that it is an extremely difficult and slow process for a stream to cut off any of its meander in a rugged region like Pennsylvania, and that it is impossible for a stream to establish a totally new course unless the conditions under which it operates are very different from those which normally affect the development of streams.

Again, as an objection to the view of Professor White, Mr. Campbell states that while it would be possible for a stream to change its course by superimposition if it were first caused to silt up its valley and then permitted to cut down again, he finds that part of the Carmichaels abandoned channel was not so silted up, and he therefore concludes that the change of course was not due to silting up and superimposition, but to local causes. Mr. Campbell's idea is that ice jams formed in glacial time and that these

grew until they formed huge dams 100 or more feet high, and that they persisted until deposits over 100 feet thick accumulated above them. In many cases these dams not only gave rise to terraces but caused the rivers to abandon their old valleys and cut new ones.

In the Amity folio Frederick G. Clapp expresses the belief that Professor White's theory—that of ponded waters throughout much of western Pennsylvania—will best account for the phenomena. He states that the upper limit of the stream deposits in all the valleys of southwestern Pennsylvania and parts of adjacent states has a vertical range of but little over 100 feet, but since Mr. Clapp's work was published the gravel has been found to lie at an elevation of over 1,200 feet on Clarion River, making the vertical range more than 200 feet.

The data gathered by the present writer, instead of lending support to any one of these views, seem rather to indicate that the high terraces and abandoned channels on all the rivers developed as a unit, through the overloading of the Allegheny in early glacial time.

The terraces may be divided into two groups, which have certain essential differences. Those of the first group are capped with glacial gravel, and are found along the Allegheny and Ohio. Those of the second bear material of local derivation, and are found on streams tributary to the Allegheny and Ohio. There are other differences which will be brought out later. In this connection it should be stated that there are a few remnants of older gravels, which lie at various elevations above the main high terrace formation, and in some places have been let down by erosion, so that they seem to connect with the much more extensive deposit below, but the older gravels have very slight extent.

TERRACES OF THE ALLEGHENY AND OHIO

The terraces of the Allegheny and Ohio are almost continuous from the mouth of the Clarion to Pittsburgh, and on down the Ohio. The gravel deposits on them are thin or absent where crossed by lateral streams; in other words, where erosion has been most severe; but enough remains to indicate clearly the position of the

original upper surface. At over one hundred places the upper limit of gravel has been determined by level, and that limit is in all cases very nearly 300 feet above present low water. The elevation of the rock floor beneath the deposits has also been determined at many points, and is found to be a little less than 200 feet above the present position of the rivers. Thus, the upper limit of gravel

TABLE SHOWING ELEVATIONS OF HIGH TERRACES IN WESTERN PENNSYLVANIA

Place	Miles from Beaver	Upper Limit of Gravel	Rock Floor	Present Stream	Upper Limit of Gravel above Present Stream.
Foxburg quadrangle					
*One mile north of Callensburg	110	1,180	1,160±	970	230
*Turniphole	108	1,170	1,120–1,160	930	240
Mouth of Clarion River	102	1,150	1,035	846	304
Mouth of Bear Run	99	1,145	1,025	840	305
Monterey	96	1,140	1,015	832	308
Kittanning quadrangle					
Redbank	81	1,100	950	810	290
Ford City	58	1,025+	885 and 980	763	262+
New Kensington quadrangle					
Tarentum	39	1,000+	975	725	275+
Carnegie quadrangle					
Allegheny	22	1,000	896	698.4	300+
Beaver quadrangle					
Beaver	0	978	900	672	306
Latrobe quadrangle					
*One mile northeast of Blairsville	80+	1,060	....	900	160
Burgettstown quadrangle					
*One and one-half miles northeast of Burgettstown	28+	1,028	1,015	947	81

*Gravel of local derivation (not glacial).

falls regularly from 1,145 feet at Foxburg to 1,010 feet at Pittsburgh; the rock floor beneath the gravel from 1,015 to about 880 feet, and the river from 845 to 700 feet. Here, then, are three approximately parallel planes, each of which slopes about 140 feet in 80 miles. In other words, the gravel formation holds its thickness of about 125 feet, and slopes in the direction of present stream flow. See table.

The pebbles are well rounded, and lie in a matrix of sand and

clay, though in some places there is so little fine material that the gravel is dug from pits and used without further washing. In such places beds of gravel are separated by lenses of clay, but on the whole the formation is homogeneous.

That the deposit is of fluviatile and not lacustrine origin seems to be shown decisively by the characters to which Chamberlin has called attention: The deposit slopes regularly with the present streams throughout their winding courses. A lake deposit would be horizontal unless affected by crustal deformation, and in that case the slope would not change direction at just the places where the course of the river changes. Second, the material is distinctly fluvial, consisting of irregularly bedded gravel which contains lenticular masses of silt and clay. A lake deposit in a valley might have deltas containing some coarse material, but in no way could coarse glacial débris, poured into the end of a narrow lake 100 or more miles long, be evenly distributed so that the resulting formation throughout its length would be homogeneous and of uniform thickness.

There seems to be good evidence also, as Leverett has pointed out, that in pre-Glacial time the Clarion was the headwater portion of the Allegheny, a divide crossing the present course of the latter stream just above the mouth of the former, and that the glacier, by cutting off the outlets of the drainage of the area to the north, forced the water to cut across the divide to the old Lower Allegheny, thus thrusting greatness upon the Allegheny basin.

Through the new cut were discharged great volumes of glacial outwash—too great for the Allegheny to transport—and the coarsest part of the débris was spread along the bottom of the valley, forming a typical valley train which had a nearly uniform thickness throughout its length. The bodies of gravel on the high terraces of the Allegheny and Ohio, then, are the remnants of this old valley train.

The overloaded condition of the Allegheny was probably due to several causes, among which the following may be mentioned as being more or less effective: First, an actual increase in load derived from (*a*) material fed more or less directly to the streams by the glacier; (*b*) débris from the cutting of new gorges across

old divides; (*c*) material brought after the ice melted, by tributaries as they cut new valleys. Second, a decrease in velocity and carrying power, produced by (*a*) the attraction of the ice mass; within a degree of the ice front this may so have changed water level that in a stream flowing away from the ice a gradient of $1\frac{3}{4}$ feet per mile might have been reduced to $1\frac{1}{2}$ or $1\frac{1}{4}$ feet per mile; (*b*) crustal deformation, due to the weight of the ice; (*c*) the divides crossed; each of these would check the velocity and cause deposits for a short distance upstream; and ice jams operate in a similar way. Third, a possible but not probable decrease in volume, arising from a change in climate. It is probable that during Kansan time the river had a larger volume than now because it was carrying the run-off from a much larger territory.

TERRACES OF TRIBUTARY RIVERS

The second group of high-terrace deposits is found on streams tributary to the Allegheny and Ohio. Those along the Clarion River may be taken as typical and described in detail.[1] At Foxburg the high gravels of the Clarion connect and mingle with those of the Allegheny, both the rock floors and the upper surfaces of the deposits connecting, without interruption (see Fig. 3). The Clarion gravels are much like those of the Allegheny, but differ from them in the following respects: First, the material is of local, not glacial, origin. Second, the thickness decreases upstream. Third, the gravels are as a whole much finer, only the base being as coarse as the glacial gravels. There are some minor points of dissimilarity, but these are the important ones in the present discussion.

In present distribution the gravels are as continuous as those of the Allegheny. There is scarcely a half-mile of the lower part of the valley where they are absent or even approximately so.

That the Clarion terraces are of stream origin is shown by characters similar to and as decisive as those of the Allegheny terraces mentioned above, and certain important features indicate the immediate cause of the accumulation of gravel. First, at the confluence of the two rivers the high-terrace gravels correspond exactly in elevation and thickness. Second, the Clarion gravel rises and

[1] See Foxburg-Clarion folio, *U.S. Geol. Surv.* (in press).

becomes thinner and narrower upstream, and at a distance of 20 miles from the Allegheny the formation has the width, thinness, and coarseness of an ordinary flood-plain deposit.

These facts suggest at once that the Clarion terraces owe their existence to conditions on the river into which that stream discharged. When the Allegheny began to aggrade, the effect was that of a gradually growing dam across the mouth of the Clarion. This caused the latter stream to drop the coarsest part of its load. The dam did not grow so rapidly as to produce a pond in the river above, but aggradation kept pace with the growth of the dam. In other words, at its mouth the Clarion built up as rapidly as the Allegheny. This is shown by the even downstream dip of the Clarion gravels and by their coarseness. If any ponded stage had existed, the deposit would have been coarse only at the upper end of the pond and would have taken the form of a delta.

But of course the dam did not affect the Clarion throughout its length. On the contrary, when the dam began to grow, its influence was felt only in that part of the stream immediately above. As it grew the area affected by it extended farther and farther from the Allegheny and the river built up to a new gradient, over which it was just able to carry its normal load. The coarser part of the gravel was dropped where the gradient changed from the old to the new. This point gradually moved upstream and the extended coarse deposit became the basal coarse part of the formation. The Clarion then silted up because its master stream, the Allegheny, was aggrading, and the elevation of its outlet was being raised. The Allegheny aggraded because of great increase in load, the Clarion because of decrease of gradient. The absolute load of the latter stream has not changed materially since the dawn of the Quaternary period.

Space will not permit of complete description of all the high terraces, but the work of the Clarion may be taken as a type of the work of those streams which discharged into the overladen Allegheny and Ohio. Redbank Creek, the Conemaugh, Kiskimenitas, Youghiogheny, and Monongahela show similar characters. On all except the smallest of the tributaries of the Allegheny, there are deposits connecting with the early glacial valley train, such

deposits rising, thinning, and narrowing upstream, and consisting of mixed coarse and fine material of local origin, the proportion of fine being somewhat greater than in the valley train. The larger the tributary the more gradually does the deposit rise and thin, for the larger streams have less fall, and there is less difference between the old gradient, with which the streams were more than able to carry their loads, and the adjusted gradients, with which the streams did neither cut nor fill.

To illustrate, certain facts indicate that in pre-Glacial time the lower 50 miles of the Monongahela had a fall of about one foot

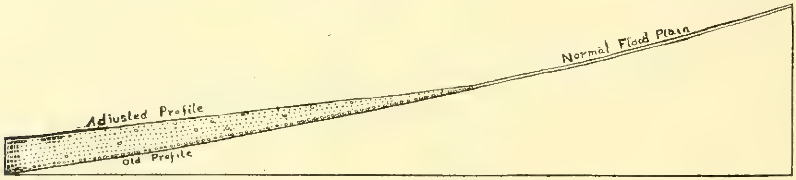

FIG. 2.—Longitudinal section of deposit on a stream tributary to one which is overloaded with glacial débris. A distinguishing character of such deposits is that they are definitely limited upstream by the convergence of the old profile in use when the stream was cutting down, and the adjusted profile with which the stream is just able to carry the load delivered to it by headwaters and side streams.

per mile, that the adjusted gradient was about 9 inches per mile, and that the valley train athwart the mouth of the river was about 110 feet thick. At this point the Monongahela fill should have been 110 feet thick, and this thickness should have decreased upstream by 1 foot minus 9 inches, or 3 inches per mile, and at 50 miles the formation should have been thinner by 130 inches, or 12½ feet. The results obtained by actual observation in the field accord very closely with these figures. The deposit is nearly 100 feet thick at the West Virginia line.

As another example, the Clarion gravels thin almost 50 per cent in 10 miles. Originally, as indicated by the base of the gravels, the stream had a fall of about 125 feet in the lower 10 miles of its course. The adjusting of the gradient reduced this to 60 feet. The difference between these figures, or 65 feet, plus the thickness of the deposit at the upper end of the 10 miles, or 50 feet, is 115 feet, which is the thickness of the deposit at the lower end of the valley.

To sum up, the inferred history of the terraces reads about as follows. The Allegheny was overloaded at a certain point. The material was spread out evenly from the place of overloading. On each tributary stream deposits accumulated, first at the point of junction with the overloaded one, then farther and farther upstream. These processes continued until the load and gradient of the Allegheny were so adjusted that the river was able to carry its load. Later, probably on account of an elevation of the land, the stream has cut through its deposit and 200 feet below the level of the old rock floor.

"ABANDONED CHANNELS"

In close association with the high terraces are the many so-called abandoned channels or side tracks to the main lines of drainage. Examples are found not only in western Pennsylvania, but along the Ohio, Mississippi, and a large number of tributary streams. Genetically these features seem to be similar, though some developed early in the Quaternary period and others later.

The abandoned part of the Monongahela valley at Carmichaels, Pa., referred to on p. 142, has been described as containing evidence of a huge local dam of ice, but to the present writer the evidence did not seem to indicate a local barrier for the following reasons: (1) The deposit thins at the position of the supposed dam not abruptly, but irregularly, and a mile or more below considerable thicknesses are found. (2) Just below the place of thinning, the formation extends up the valley side to the altitude of the upper limit of gravel, and a little farther away are extensive bodies of the deposits, fully 100 feet thick. (3) The thinner parts are found at a place where erosion has been very severe—where the gravel has been dissected by a good-sized tributary. It appears, therefore, that the thin part of the deposit is simply a result of irregular clearing-out of the old valley by the tributary and is a feature to be expected. The stream seems to have cut down quickly through the silt and gravel, but when it came to hard rock it hesitated, meandered a little, and then cut down farther, leaving the shelf covered with pebbles and bowlders concentrated from the original deposit. The fact that just below the site of the dam the formation is found

today extending up on the side of the valley and a few miles away the full thickness of over 100 feet is present, is evidence that the deposit was formerly 100 feet deep here as it is elsewhere. There could scarcely be any other possibility except that the valley-side deposit represents an older fill, and there is no foundation for such an assumption.

A theoretical consideration of the question of local ice dams yields interesting results. The possibility of an initial ice jam is not to be questioned. Moreover, the supposition that such a jam might be large in a northward or iceward flowing stream in a subglacial climate is reasonable and is supported by known conditions on the McKenzie and other streams which work under somewhat similar circumstances.

But the ice dams in this case must have been several times as high as the highest known and must have persisted through many summers warm enough to melt back the thousands of feet of ice in a continental ice sheet. Indeed if we assume that the Monongahela carried the same amount of suspended matter which it carries today (in all probability it did not carry so much), that all its load of undissolved matter was dropped, and that immediately after the reservoir became filled the dam went out, we get a minimum estimate for the life of the dam of about 1,000 years. If only a quarter of the material were dropped the time would be 4,000 years.

During this time the run-off of the basin must have passed over the dam, for if the dam had suddenly risen above the height of cols in near-by divides, the lake immediately behind the dam would not have been silted up. Moreover, considerable coarse material is found just above the supposed dam, indicating that there were strong currents and that only a small fraction of the suspended matter was dropped.

The hypothesis of an ice dam, therefore, involves the assumption that the Monongahela, which since early glacial time has, with a very low gradient, removed rock material to a depth of 200 feet for more than 100 miles, was for centuries unable to cut through or undermine these blocks of ice over which its gradient and eroding power must have been that of a cascade or waterfall. The assumed floor of the valley below the site of the dam is 60 feet below

the top of the fill above the dam. The drop in water level must have been as great or greater, and yet the dam must have withstood the pressure and the wear year after year for thousands of years.

Parker oxbow.—One of the most famous of the abandoned valleys is the old oxbow at Parker's Landing (see Fig. 3). It was first described in detail by Chance (*Second Geol. Surv. of Pa.*, Rept. VV, 1880, 17–22). He calls attention to the disproportionate size and breadth of the valleys of the two small streams which now flow from the oxbow, and also to the fact that between the heads of the streams there is low swampy ground. Glacial gravels of probable Kansan age are found almost continuously around the loop and in some places the deposit is over 50 feet thick. Chance inferred that at the time of the earliest ice advance this oxbow was occupied by the Allegheny River, and at a subsequent time the neck was severed.

G. F. Wright held that this channel was formed and abandoned before glaciation, and that the glacial material now found in the oxbow was deposited there at a time when the Allegheny, being overloaded with Kansan outwash, aggraded up to a position somewhat above the oxbow; that the gravel was carried into the ends of the loop, but the river never reoccupied the entire loop. Wright has long advocated the idea that the Allegheny was cut to about 50 feet below its present channel in pre-Glacial time, and that the glacial valley train was thus about 350 feet thick, filling the inner gorge and part of the broad valley above.

Chamberlin and Gilbert studied the problem in 1889, and their conclusions agree essentially with those of Chance, and are found in *Bulletin U.S. Geological Survey No. 58*, 31.

In 1894 Wright again published a paper (*Am. Jour. Sci.*, 3d ser., XLVII, 173–75) in which he holds to his previous conclusions.

In 1900 E. H. Williams presented a paper at the Albany meeting of the Geological Society of America (*Bull. G.S.A.*, XII, 1900, 463) in which he agreed with Wright that the river has not occupied the oxbow since the beginning of the Glacial period, but he went so far as to hold that the river never did flow around the so-called oxbow. He ascribes the feature to the work of two small streams which "rise on opposite sides of a low col and de-

FIG. 3.—Topography of "Parker oxbow" and vicinity. (Shaded part shows area occupied by high-terrace gravel.) (From Foxburg, Pa., topog. sheet, *U.S. Geol. Survey.*)

bouche into the Allegheny gorge within a mile of one another, and in Glacial time these two valleys were filled by overwash deposits mingled with material from the immediately adjacent slopes." He states also that the rock floor of the abandoned channel is not level, but falls down rapidly toward the river. He does not, however, explain the fact that the col between the heads of the two streams is low and swampy, whereas there is not a case of two large streams rising in an area of swampy ground in the whole unglaciated area of western Pennsylvania, and he says nothing about the broad steep-walled valley through which the small streams flow.

Frank Leverett (*U.S. Geol. Surv. Mon. 41*, 242) considers E. H. Williams' view "more consistent with the features than the one presented by Chance," and says further (apparently misinterpreting Williams' view): "It refers the opening of the double channel, resembling the forks of an oxbow, to a shifting of a smaller tributary of the Allegheny from one side to the other of a low hill that stood nearly opposite the point at which the tributary entered the valley."

The data gathered by the writer indicate, first, that the so-called Parker oxbow is an abandoned channel of Allegheny River, and so is properly called an oxbow. The characters which force such a conclusion are: (*a*) the depression has the size and shape of the Allegheny valley, having a comparatively uniform width of about a mile, and bounding walls from 100 to 300 feet high; (*b*) the shape is a broad smooth curve with the side of the valley inside the loop gently sloping, and that outside high and steep like the present valley around curves of the river (it resembles, for example, the curve of the Clarion 1 mile south of Turniphole, Foxburg quadrangle); (*c*) a current with something like the strength of a river must have flowed around the bend, for pebbles up to 6 inches in diameter are found at the most extreme part of the loop.

Second: The abandoned channel was occupied in a part of Kansan time. The presence of Kansan outwash on the floor, which is at nearly the same elevation as the floor under Kansan material near by, indicates that the last great event before the abandonment of the oxbow was the advance of the Kansan ice

sheet. The abandonment took place before the stream began again to cut down, for deposits are found around the loop almost as high as the highest gravel. The broad valley around the oxbow was cut previous to this time. One can only conjecture how long a period of time was necessary for this.

There is some evidence that the rock floor of the east end of the loop is higher than the Parker strath. If this be true the oxbow must have been developed either in pre-Kansan time, before the stream had cut as low as the Parker strath, or after the Allegheny had aggraded until it was high enough to take this route. However this may be, the close association of the abandoned channel with the high terrace, and the occurrence of Kansan material in the channel, show that whenever it was formed, it was occupied and abandoned in Kansan time.

Third: The length, depth, and narrowness of the rock channel through which the river now flows across the neck of the oxbow suggests that the oxbow was not cut off in the way that streams ordinarily cut off their meander, but points rather to superimposition. The present valley across the neck of the abandoned channel is a narrow rock gorge over a mile long, and the top of the gorge extends up to the level of the highest part of the old channel.

Another abandoned valley which is thought to show the method of development very well is found on the Allegheny, a few miles northeast of Pittsburgh, and opposite Verona. The topography suggests at once that this feature is a cut-off loop of the Allegheny, and it is found on a level with the high terraces. The width is nearly as great as that of the old valley of the Allegheny, and glacial gravels are found in it. But on closer inspection it is found that the width of the valley and the thickness of the deposit decrease rapidly away from the present course of the river, and this through a rise in the rock floor. Also there is an impressive amount of fine material and a scarcity of bowlders. Finally, at the extreme end of the loop the old valley, if such it be, is very narrow, and the deposit but a few feet thick.

The meaning of these features seems quite evident. At the time the Allegheny began to aggrade, the position of this loop was occupied by two small tributary streams. The divide between them

was, at one place, a little less than 100 feet above the river-valley floor. As the river rose it dropped some coarse materials in the ends of the tributary valleys, but a mile away the ponded water was quiet and the deposit fine. This process continued until the Allegheny reached the elevation of the lowest point in the divide between the streams, about 3 miles away. Then the river current was separated and a part flowed slowly up one tributary and down the other, carrying some coarse and much fine material (varying from season to season) and shaping the col into the form of a valley. Finally the river cut down again, abandoning the course which it had occupied temporarily for the much shorter original course.

A part of the history of the loop is reflected also in its present drainage. When the river left it, the run-off was naturally in the direction in which the river had flowed, out one arm and back down the other. But a new small tributary in the position of the upper one of the old ones is now cutting back into the upper end of the abandoned valley, driving the head of the other stream back and annexing a part of its unnatural drainage basin.

All of the other abandoned parts of the valleys of this region have been examined carefully and seem to have been developed in the same way—by silting up and redissection—and the process is the same whether the case be on the Allegheny or on one of the tributary streams. In many cases the new courses made available by the silting-up of the old channels were about as direct as the old, and in certain of such cases the stream cut down in its old course, while in others it assumed a new course. Thus some of the abandoned valleys mark courses temporarily occupied by the rivers, while others show old and long-used courses. It is a significant fact that the changes were, in nearly every case, from a longer route to a shorter one. This would scarcely have been true had the rivers been driven from their courses by ice dams. There are some cols which stand just a few feet higher than the highest gravel, and these were, of course, never crossed by the rivers. Indeed, if aggradation had proceeded 50 or 100 per cent farther there would have been an amazing network of long and devious "abandoned" valleys.

SUMMARY

Summarizing, the method of development of the high terraces and abandoned parts of valleys of western Pennsylvania seems to be as follows: (1) The development of a valley train over 100 feet thick, along the Allegheny and Ohio; (2) from the beginning the aggradation of this stream produced an effect felt on every tributary, and a portion of each, beginning at its mouth and extending gradually upstream, became silted up. (The lower end of each tributary valley thus took on a form resembling the half-filled character of the valley of the master stream.) (3) As the rivers built up they found themselves flowing at the height of one after another of the lowest places in near-by divides, and at such times and places the currents were divided and the cols were occupied. This overloaded condition of the streams lasted a long time and there were many fluctuations, for at some places, as at Pittsburgh and Belle Vernon, there are two or three well-developed valleys side by side. (4) When final redissection began, the rivers chose the channels momentarily most desirable. In most cases the short route was the principal factor in the choice, but in others the largest current at the time and other comparatively trivial conditions determined the courses of the streams. As in all cases of superimposition, the resistance of underlying rock played no part in their location, and at many places the rivers soon found themselves sawing into hard rock where near by were courses through unconsolidated materials.

REQUISITE CONDITIONS FOR THE FORMATION OF ICE RAMPARTS

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In a recent paper[1] Mr. J. B. Tyrrell, late of the Geological Survey of Canada, has made the assertion that though he has now for many winters made observations on and about the Canadian Lakes, he has never detected any evidence of ice push against shores as a result of expansion. He thus discredits the accepted explanation of ice ramparts. To one who has in other localities seen the ramparts *in process of formation* from this cause, it seems important to supply an explanation for the failure of such an experienced and careful observer as Mr. Tyrrell to observe the same phenomenon.

The quite obvious fact is that ice ramparts are greatly restricted in their occurrence, a number of special conditions being essential to their formation. Mr. Tyrrell's paper fortunately shows that some of these conditions were lacking in the districts which he studied.

In order that these requisite conditions may clearly be understood, it will be necessary to give in brief outline the theory of formation of normal ice ramparts through ice expansion. The initial ice cover of the winter season on our northern lakes usually forms with only moderately cold air temperatures. These may be assumed to be but a few degrees below the freezing point, and the cover, once formed to a thickness of an inch, grows quite slowly from the under surface. After it has acquired a considerable thickness, the arrival of one of the "cold waves" contracts the ice cover by lowering its temperature through contact with the colder air layers. Under this contraction fissures open in the ice to the accompaniment of loud rumblings, water rises to fill them and is

[1] J. B. Tyrrell, "Ice on Canadian Lakes," *Trans. Can. Inst.* (1910), IX, 1–9 (reprint), pls. 1–6.

quickly frozen in the prevailing low temperature so as to form intercalated "planks" of younger ice. The lake cover is thus again completed at a low temperature, so that a "warm wave," *if it can quickly communicate its temperature to the ice*, causes an expansion which according to Tyrrell amounts to one to three inches per mile per degree Fahrenheit. Thus expanded the ice cover is too large, and a push is exerted against the shore *if the cover is a structure competent to transmit the stresses induced in it.* The range of action of this push, and the consequent *size of the ridge raised upon the shore will depend upon the number of times the process is repeated;* for each alternation of "cold" and "warm" wave introduces a new series of wedges into the ice cover and correspondingly extends its margins.

To recapitulate: (1) there must be a wide and probably also a relatively sudden alternation of lower and higher air temperatures over the lake: (2) these temperature changes must be promptly communicated to the ice; (3) the ice cover regarded as a girder must be competent to transmit the stresses to the shore; and (4) for large effects the alternations of temperature must be several times repeated. Obviously, also, the shores of the lake must be of such form and materials as to be subject to movement under stresses below the crushing strength of the ice itself.

The first and last conditions are meteorological and can be determined for any given district. Not only is a severe winter climate essential, but there must be an alternating occurrence of cold and warm waves.

The second and third conditions are crucial. In Buckley's studies of ice ramparts at Madison, Wisconsin, the most thorough that have been made,[1] it was found that ramparts seldom formed during seasons when the lakes were snow covered. The probable explanation of this is that snow blankets the ice and prevents a *quick* communication to it of the air temperatures above the snow surface. We have here emphasized the element of time, for the reason that studies in Greenland show that air temperatures are *slowly* communicated downward through snow blankets to very

[1] E. R. Buckley, "Ice Ramparts," *Trans. Wis. Acad.* (1901), XIII, 141–62; pls. 1–18 (discussion by C. R. Van Hise).

considerable depths. It is well known from studies of the "fatigue" of materials under stress that they often yield to slowly acting stresses that would be transmitted undiminished in intensity if quickly applied. Snow blanketing of the ice, from the evidence in Mr. Tyrrell's paper, would appear to be very general within the districts which he studied.

Further limitations upon the formation of ice ramparts are imposed by the third condition—the incompetency of the ice cover as a transmitter of stresses. With the ice serving as a strut,

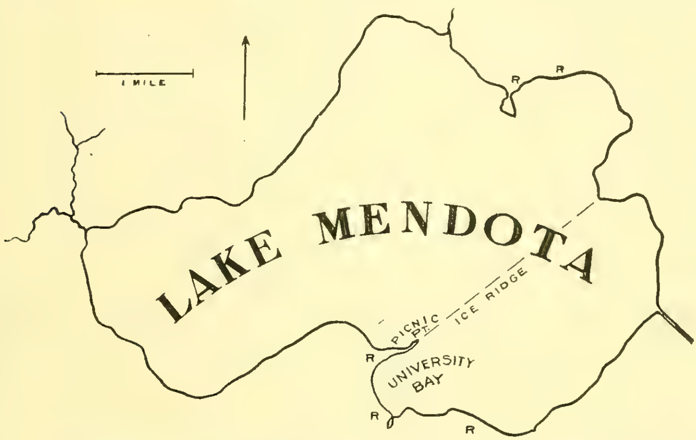


FIG. 1.—Sketch map showing the position of ice ramparts and of buckled ice ridge formed on Lake Mendota at Madison, Wisconsin (based on Buckley's Map).

its push can be transmitted effectively *only when the cover is maintained as a plane surface.* Lack of homogeneity or of absolute uniformity in strength, and variation in form of the surface at which stress is applied, will with increasing length of beam introduce an important stress component tending to buckle the beam and dissipate the energy transmitted by it—the competency of a strut to transmit stresses is inversely as its length. Experience shows that lakes or arms of lakes which are much over a mile and a half across do not develop important ice ramparts. On Lake Mendota at Madison, the best ramparts are found upon the shores of University Bay, which is about three-fourths of a mile across. Outside this bay the lake ice is raised each winter into a sharp

ridge extending from the outer margin of the bay (the peninsula of Picnic Point) across the wide portion of the lake to the opposite shore, and about this section no ramparts are developed (see Fig. 1).

Ice ramparts can thus form only on shores of lakes which have relatively small size or on small bays of larger lakes, though a width of at least half a mile is probably necessary in order to secure sufficient dilatation of the ice cover to make ramparts of appreciable size.

Anything which tends to deform the ice cover from a perfect plane will effectively destroy its competency as a girder, and then no ramparts will form. Mr. Tyrrell has shown in his valuable paper that young lake ice will support, without bending, less than its own thickness of dry snow, and that the ice on Canadian lakes is bowed down under its load of snow to such an extent that water comes to the surface through cracks and further increases the bending.

To sum up, the heavy snow cover alone would by blanketing the ice, but probably even more by bending it, effectually prevent the formation of normal ice ramparts. As already stated, such ramparts may actually be seen in process of formation during a warm wave in any favorable winter about Lake Mendota at Madison, Wisconsin.

It is fully realized that rafts of floating ice drifted by the winds at the time of the spring "break up" do also produce small bowlder ridges on shores which bear a close resemblance to some of the types of normal ice ramparts.

THE TERMINAL MORAINE OF THE PUGET SOUND GLACIER

J. HARLEN BRETZ

I. GENERAL CHARACTER OF THE COUNTRY SOUTH OF PUGET SOUND

The region of Puget Sound, inclosed between the Olympic and Cascade ranges, is a heavily drift-covered lowland. The drift is deeply incised by broad valleys of meridional trend, some occupied by arms of the Sound, some by lakes, and others by streams. The summits of the plateaus and hills of drift accord in a general level so that, seen from overlooking mountain peaks, the region appears to be a vast plain, interrupted only by a few rock hills, remnants of the preglacial topography rising above the drift.

Immediately south of the Sound the drift assumes a different facies. The trough valleys disappear and the plain becomes continuous and is widely covered with gravel outwash. It is still a part of the great Puget Sound drift plain. It is diversified with morainic eminences occasionally, of a character different from that of the drift hills lying between the valleys of Puget Sound farther north. The most southerly extended of these hills is a belt which constitutes a part of the terminal moraine of the Puget Sound glacier.

Beyond the southern portion of the Puget Sound depression is an abrupt transition in the topography. Rock hills of preglacial sculpture, lying beyond the limit of glaciation, begin here and continue southward past the Columbia. In western Washington no other such area of low rock surface occurs as must here exist beneath the heavy drift mantle of Puget Sound.

On the southeast, the area is overlooked by the magnificent Tertiary volcano Rainier. On the south is a region of rock hills bearing no group name. They are drained by the upper Des Chutes and the Skookum Chuck rivers and have a maximum altitude of about 2,000 feet. Farther west lie the Black Hills, whose highest altitude is probably not greater than 2,000 feet.

These hills are bounded on the east and northwest sides by low, wide valleys which constituted the two chief routes of glacial water discharge from the basin of Puget Sound. The Olympic foothills rise farther northwest in the main Olympic Range. At the time of greatest extent of the ice, the northern slope of the Black Hills was overridden and a lobe extended down on either side, the hills determining a broad re-entrant in the ice front.

II. PREVIOUS WORK ON THE MORAINE

In a general way, the glacial drift in Puget Sound has long been known to terminate some distance south of Olympia, and the gravel plains have been commonly recognized as outwash deposits from the ice. No detailed work, however, has been done in the region except by Willis and Smith on the Tacoma quadrangle.[1] Here the contact between Pleistocene deposits from the glaciers of the Cascades and Mt. Rainier and the Puget Sound drift has been traced along the northwest flank of the volcano to the southern edge of the quadrangle.

Warren Upham has described,[2] from a hasty reconnaissance, what he believed to be the terminal moraine lying between the base of Mt. Rainier and the Black Hills. He interpreted the remarkable gravel mounds of the outwash plains of the region as morainic topography of peculiar type.

No observer, so far as the writer is aware, has previously noted the existence of the western lobe of the glacier, lying between the Olympic Mountains and the Black Hills.

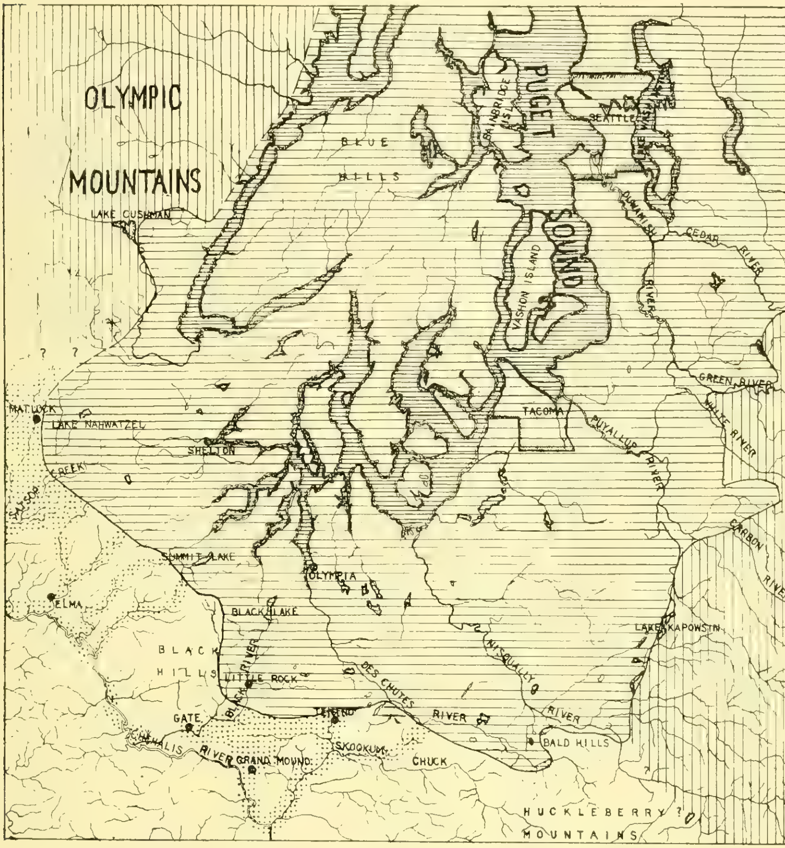
III. MORAINE COURSE ACROSS THE GEOSYNCLINE

The westernmost geosyncline of North America is regarded by stratigraphers as finding its representative on the Washington coast in the Puget Sound depression. Were it not for the accident of glaciation, this structural valley would today embrace a broad inland sea, but the thick drift deposit constitutes a filling sufficient to maintain most of the surface above sea-level. The terminal

[1] Bailey Willis and G. O. Smith, "Tacoma Folio, No. 54," *U.S. Geol. Survey.*

[2] Warren Upham, "Glacial and Modified Drift in Seattle, Tacoma and Olympia," *American Geologist,* XXIV, No. 4.

moraine is built far enough to the south to lie in general over rock surfaces above sea-level; indeed, the moraine forms a fairly con-



GLACIATION OF PUGET SOUND

Horizontal Ruling ---- Extent of Vashon Glaciation
Vertical Ruling ---- On East — Cascade Neve and Ice
On West — Olympic Neve and Ice
Dotted Areas ------ Extra-morainic Vashon Outwash

0 10 20 30

stant boundary between the depressed region to the north, now drift filled, and the rugged, stream-carved rock hills southward.

The field work on which this paper is based has been done under some difficulty because of the undeveloped nature of the country,

and its incompleteness must largely be charged to the same reason. Large tracts about Puget Sound are yet covered with virgin forest whose density is such that passage for any considerable distance is next to impossible. The lack of roads, trails, and inhabitants over many square miles forces the investigator to shoulder his pack of blankets and food, and travel the country on foot. Detailed work is not practicable under these circumstances. It will probably be years before the moraine can be mapped with accuracy, since the task must wait on the agricultural development of the country.

On the eastern margin of the Tacoma quadrangle, Willis and Smith[1] found a broad sheet of till spread by a piedmont glacier from the Cascades. The contact between this drift sheet, named the Osceola till, and the Vashon or youngest till sheet of the Puget Sound glacier was found to be marked by a belt of hummocky topography of morainic aspect, considerably different from that of the ground moraine on either side. No definite marginal or interlobate moraines were found, the phenomena being apparently referable to subglacial accumulation. Short eskers were a notable feature.

This study has taken up the continuation of the contact between local glacial deposits, and those far traveled down the Puget Sound depression from the north, on the south edge of the Tacoma quadrangle in a densely wooded country traversed by a few secondary roads and one highway, the Mt. Rainier automobile road. The geological map of the Tacoma folio maps the Rainier Pleistocene drift on the south edge of the quadrangle, farther west than the writer has found it. The automobile road follows a north to south course for 5 or 6 miles, parallel to and about 6 miles west of Lake Kapowsin, and for this whole distance traverses the till plain of the Puget Sound Vashon glacier. Northward toward Tacoma are extensive areas of outwash gravel deposited during the recession of the Puget Sound ice. The till plain rises southward from the outwash with an abrupt morainic slope, ascending 200 feet in one mile. The slope is thrown into several successive ridges of till trending east to west, on the south sides of some of which were

[1] Bailey Willis and G. O. Smith, *op. cit.*

distinct kames. The till is the characteristic blue-gray arenaceous material, with laminae and rounded cobbles, which is identified throughout the Puget Sound country as Vashon. The presence of numerous varieties of rolled granite cobbles in the moraine and in the plain southward is a safe criterion for the identification of the till as the Vashon rather than the Osceola till of the Cascades. The moraine ridges on its northern flank and broad till plain lying southward are topographic features in accord with this interpretation. Though the boundary between Vashon and Osceola till was not located, it obviously lies between the Mt. Rainier highway and Lake Kapowsin, the lake lying at the base of the foothills of Mt. Rainier.

The dominance of Puget Sound ice at the western base of the Rainier foothill country is proved conclusively by the common occurrence of bowlders and cobbles of several granitic types characteristic of the drift of Puget Sound and unknown to the adjacent Cascades.

The postglacial gorge of Nisqually River, 300 feet in maximum depth and with vertical and even overhanging walls, is two miles long and occurs where the river enters the area of Puget Sound drift. A 40-foot section of outwash, containing frequent Vashon drift materials, overlies the rock floor in which the canyon is cut at LeGrande. Farther up the canyon no drift was found.

A trail crosses the divide between the Nisqually and Des Chutes rivers just south of the canyon noted, entering the latter stream at the headwaters. Scattered granitic bowlders of Vashon drift were found up to an altitude of 1,220 feet on the Nisqually side, but no traces of drift were found in the remaining 200 feet of ascent or in the valley of the Des Chutes on the other side until the altitude of 1,200 feet was reached, a few miles down from the headwaters. Here scattered erratics occur on the hillsides, and at 900 feet is a level terrace composed of fine material with interspersed pebbles, probably a lacustrine deposit caused by the ice entering the lower valley and blocking the drainage.

Two miles below this terrace, whose soil has determined the location of several small farms in the wilderness, is found the terminal moraine of the Puget Sound Vashon glacier. The surface is exceed-

ingly bowldery, granite is very abundant, kettles containing lakelets and bogs are common, and the subsoil is typical Vashon till. The margin of this bowldery drift may be traced about the west and north of the Bald Hills from the Des Chutes to the Nisqually River and is in places thrown into sharply defined ridges. Occasionally the forest seems growing on one gigantic bowlder heap. A preglacial valley descending to the northwest has been dammed, giving rise to Little Bald Hill Lake, a picturesque body of water in the heart of the wilderness. Another such valley has three morainic ridges thrown across it at descending altitudes, a marsh or alluvial flat lying behind each ridge. Pronounced relief of the moraine on the north slope of the Bald Hills was found, but the unbroken forest prevented satisfactory examination.

The same difficulty of examination is presented by most of the country from the Bald Hills west to Tenino. In general, the drift-covered area bears the farms and roads, the region immediately beyond the ice limit rising in rocky hills which constitute the divide between the Des Chutes River and the Skookum Chuck. A traverse across this divide found the moraine disposed in bowldery ridges along the base of the hills with a marginal drainage channel separating the frontal ridge from the bold rock hill slope. No erratic material or evidence of ice action was found on the ascent to the divide crest, the glacier of Puget Sound having succeeded in barely reaching the northern base of the hill region.

The town of Tenino is situated on an area of gravel outwash lying immediately south of the moraine. The rock hills die away toward the west just south of the town and glacial drainage escaped southward to the lower Skookum Chuck through a broad, gravel-filled valley. Glacial outwash was also carried westward from Tenino toward Grand Mound and Gate to join the extensive areas there outspread.

The Skookum Chuck bears a train of glacial gravel which entered it somewhere in the unsurveyed region of the Huckleberry Mountains, presumably from Mt. Rainier's Pleistocene glaciers. But careful search revealed absolutely no granite or sedimentary metamorphics in this gravel for a distance of 6 miles along its course. Only when the western limits of the rock hills were approached,

and below a low pass across the divide to the Des Chutes River, was Puget Sound glacial gravel found in the Skookum Chuck valley.

Clear Lake, at McIntosh station, 4 miles east of Tenino, lies in a marginal drainage channel discharging westward into the outwash gravel area at Tenino. The terminal moraine lies immediately north of this lake. North of Tenino, the moraine is of a character considerably changed from that in the Bald Hill region. It has here become a single massive till ridge on the plain, and surface bowlders are not sufficiently numerous to attract attention. It is two miles wide and 250 feet above its base on both north and south sides, the highest point examined reaching 550 feet A.T. On each side, it is flanked by an outwash gravel plain bearing peculiar tumuli. The till mass appears to cover several rock knobs and hills, whose existence may have in some measure determined its location and relief. Both east and west of Tenino, quarries in sandstone have been opened on the slopes which rise farther to the north in the moraine. The road north from Tenino to Olympia cuts into decayed shale strata *in situ* at the summit of its grade across the moraine at about one-half the maximum height of the moraine, and at McIntosh rock outcrops occur on the south base of the moraine.

The hills which rise south of Tenino were carefully examined for drift materials. Three distinct terraces of outwash gravel were found, occasionally showing forests beds descending southward toward the Skookum Chuck. The highest gravel lies 360 feet A.T., and above it drift abruptly ceases.

Flanking the frontal margin of the moraine from Tenino west to Black River is an extensive area of outwash gravel, known as the Grand Mound Prairie. It is entirely barren of forest growth and almost useless for any agricultural purpose because of the coarseness and depth of the gravel. At the contact between moraine and outwash examined no apron structure was found. The gravel plain apparently was built by outwash occurring through breaks in the moraine ridge and not by outflow from the ice edge when standing at its maximum limit.

The whole region south of Puget Sound bears much outwash, both

extra-morainic in position and lying back of the ice limit. These areas are all alike in being natural prairies because of the coarseness of the soil and in bearing a surface deposit of black silt of variable thickness. Many of them exhibit a very interesting surficial development into mounds of fairly uniform size and distribution composed of mingled gravel and silt without stratification. Where typically developed, they resemble a field of closely spaced haycocks. Their origin is not clear. Grand Mound Prairie bears these tumuli over a considerable portion of its extent.

Some distance back from the frontal edge of the terminal moraine between Tenino and Little Rock a new railroad grade affords frequent exposures of the Vashon till overlying drift of much greater age and with bedrock often appearing beneath the drift. Hills of the moraine occur on the east side of Black River a mile south of Little Rock, while across the river on the west, a morainic tract of low relief occurs about a mile wide. In this tract is a splendid exposure of Vashon till highly charged with rounded gravel which is doubtless overridden and incorporated outwash material.

Mima Prairie, southwest of Little Rock, is another part of the outwash gravel plain and forms a sharp re-entrant angle in the surface till exposures, though hardly recording such an ice margin form, the till being probably buried beneath this northward angle of the outwash. Between Mima Prairie and the Black Hills, unweathered Vashon till was observed in a gravel pit with a thickness of three feet overlying a very red and decayed till of undetermined depth. Small pebbles of the latter were often easily cut in two with a knife, while those of the overlying Vashon were firm and unweathered.

No drift is found back in the Black Hills except a sprinkling of pebbles in re-arranged residual material on the slopes which face the broad drift plain eastward. The region is exceedingly difficult to examine, the forest being almost impassable. Entrance into the hill region is gained on a logging railroad and on various trails. One road crosses near the northern part of the hills, passing west from Olympia close to Summit Lake. Drift has been found near this lake on the north slope of the hills up to an altitude of 1,460

feet, falling short a few tens of feet of reaching the summit. No till has been found in the valleys of any of the south-flowing streams of the region.

Summit Lake lies in the upper part of a preglacial valley, the lower southern portion of which bears a drift filling. The ice sheet certainly overrode the divide at the northeast of Summit Lake but it brought over no drift. Farther south, however, the valley opens into a larger one trending east and west, and from both directions in this, till was carried into the Black Hills. Again the relation of agriculture to the drift is illustrated in the occurrence of several small farms on the broadened valley floor produced by drift filling while elsewhere the region is covered with primeval forest or the waste of logged-off land.

At least two distinct valley trains cross the western part of the Black Hills to the Chehalis River, the larger of these being a filling so complete that several rock hills rise like nunataks from the gravel plain. This enters the Chehalis valley at Elma, in the vicinity of which it is deeply incised by creeks, its structure being thus plainly revealed. A feature of the gravel is the prevailing reddish color, fairly uniform throughout the mass. The freshness of the pebbles and the youthfulness of drainage on the plain, however, show this staining to be due to some other cause than age. The Vashon till near the head of this valley train is also deeply red while its pebbles are fresh. The explanation is thought to be found in the incorporation of residual material from the basalt rocks of the Black Hills.

The country lying between these hills and the Olympic Mountains is practically a great gravelly waste. The forest is thin over large areas and open prairies occur in the region south of Hood's Canal. The moraine hills when found are often largely buried in outwash and the extreme limit of the ice as mapped is consequently only approximate, being based on the occurrence of till outcrops above the gravel plain. No definite ridging tangential to the ice margin was observed in the till hills seen, though their occurrence forms a zone a few miles wide, whose outer margin has been indicated as the limit of Puget Sound ice to the west.

The character of the till, where exposed in railroad cuts and

stream valleys, appears identical with that shown in the vicinity of Seattle, on the slope of the Bald Hills, and in other widely separated regions. The matrix is somewhat sandy, the pebbles and bowlders are rounded, and large erratics are rare. Granite of various kinds is abundant, though granite is not known in the neighboring Olympics. The till is seen to overlie fresh gravel in a few sections with a thickness of about three feet. Its altitude probably does not reach much above 450 feet A.T.

Lake Nahwatzel lies in a decidedly morainic area, the monotonous gravel plain giving place to rolling hills of till which rise 50 feet above the lake surface. These morainic hills lie probably over the lowest preglacial rock surface between the Black Hills uplift and the Olympic foothills, and in such a situation we may find an explanation of the more pronounced morainic expression.

The till along the margin from Matlock to the Black Hills often shows a large proportion of deep red clayey material intermingled with fresh pebbles. The presence of such material, doubtless from the incorporation of the residual soil of basalt of which there are frequent outcrops, is to be expected near the ice margin providing the ice was overriding a region previously unglaciated.

The approximate moraine course from Matlock northward bends abruptly back toward Hood's Canal, the greater length of which is closely bordered by the Olympic Mountains on the west. The extent to which Puget Sound drift penetrated into the valleys of these mountains is known in but one case, that of the Skokomish River. Rock along this stream's course is practically absent below Lake Cushman, while the mountain walls rise almost from the lake shores on the upstream side.

Puget Sound drift of Vashon age composes an extensive plateau 400–800 feet above Hood's Canal, extending back from Lilliwaup Creek directly west to Lake Cushman and also southward to the broad, pre-Vashon lower Skokomish valley. One large rock hill rises through this till plateau just south of the Lilliwaup, otherwise the surface is of rolling ground moraine with occasional shallow kettles. Across the Skokomish to the west are foothills with little or no drift. To the south of the great bend of this stream, extensive

outwash gravels begin, continuing to Shelton in one direction and across the Puget Sound divide to the Satsop in another. In this latter direction, the outwash largely buries the moraine near Matlock and becomes extra-morainic in its further extent.

On the east side of Lake Cushman, the till plateau becomes ridged and kettley, though a dense forest prevents satisfactory examination. The morainic character is best seen along the trail from the head of the lake to Lilliwaup. The material on the lakeward face of these ridged drift hills nowhere contains granite, though two very careful examinations were made. In but one place are granite pebbles found on the shore or in the immediate vicinity of the lake, this being in the bed and delta of the largest stream entering the lake from the northeast. Yet a mile back from the lake, to the east, granite bowlders are found lying on the surface, becoming very numerous two or three miles farther east.

The limit of the Puget Sound drift is thus seen to lie close to the lower end of Lake Cushman, the basin of which is caused by the damming of the Skokomish River valley. The inner slope of the drift dam is probably faced with the terminal deposits of the Skokomish valley glacier, which was unable to advance farther in the face of the overwhelming mass of the Vashon glacier. It may have earlier deployed farther out on the plain, but if so the deposits are buried beneath the Vashon drift. That a valley glacier must have existed back of the drift dam of Lake Cushman when the Puget Sound ice was at its maximum is evident, else the lake basin would have filled with outwash. A till with very angular débris, none characteristic of Puget Sound drift, lies back of the drift dam on the slope of Mt. Ellinor, immediately north of the lake. It is estimated to reach 500 feet higher than the lake surface.

As shown on the map, the western margin of the Puget Sound glacier north of Lake Cushman is approximate only. The mountains rise close to Hood's Canal throughout the remaining distance included in the accompanying map, and in all probability there existed no embayment of Puget Sound ice in the other river valleys entering the Canal comparable to that of the Skokomish valley.

IV. GENERAL CONSIDERATIONS

Considering the altitudes of the terminal moraine only where facing driftless country to the south, its crest is found to have no great range in elevation above the sea. On the north slope of the Bald Hills, near the headwaters of the Des Chutes River, the moraine crest is probably nowhere more than 900 feet A.T., though erratics occur 320 feet higher. Near Tenino, where the moraine is most typically developed on the plain, the crest is probably less than 600 feet in altitude. The existence of buried rock hills in the moraine in this region has been noted. At Little Rock, the moraine surface on the west side of Black River can hardly have been lowered by erosion of escaping glacial water or subsequent stream action, and is approximately 150 feet above the sea, the lowest altitude in the moraine. From this altitude is a descending slope southward, on which the ice ceased to advance. The opposing northern flanks of the Black Hills, deeply cut by valleys, did not permit assumption of the moraine form. Drift, however, has its upper limit in the re-entrant angle which they produced, at an altitude of 1,460 feet. The flattened lobe northwest of these hills has its moraine hills about Lake Nahwatzel at 450 feet A.T. Puget Sound and Olympic drift damming Lake Cushman reaches observed heights of 950 feet above the sea.

The data available for an estimate of the thickness of the ice and its frontal slope are meager. Three miles from Little Rock, the glacier left its till at the eastern foot of the Black Hills at an altitude of about 150 feet. From here it is 10 miles north to the upper drift limit near Summit Lake, at 1,460 feet A.T. The slope in this instance is approximately 130 feet per mile. Fifteen miles east of Seattle rises the peak of Mt. Issaquah, about 3,000 feet A.T., whose frost-riven summit bears no residual soil comparable to that found on hills of much the same lava rock beyond the limit of the drift. Scattered erratic pebbles were found on the summit, their number increasing on the lower slopes. With the maximum depth of the Sound near Seattle at 964 feet, we may conclude that in the latitude of Seattle the glacier attained a thickness of 4,000 feet, allowing very little for central surface convexity, which would increase the estimate an unknown amount.

Evidence of the lack of vigorous movement near the frontal margin of the glacier is shown in the occurrence of deeply decayed material overridden by the ice. Shale strata, profoundly decomposed, are exposed east of Little Rock. Though slightly crumpled and in one case bearing an intruded arm of the till, this incoherent and rotted shale has been but little eroded by the ice, though it is two or three miles back from the moraine front. West of Little Rock, where Vashon till is found at its farthest southern extent along the Black Hills, a knob of old red till is exposed beneath it. Depth of weathering and staining are the same on the slopes as on the summit of this knob, hence the inference that no erosion of the projecting softened till was produced by Vashon ice.

The accompanying map indicates only the extra-morainic outwash. Great areas lie within the moraine limits of essentially the same character and age. In the case of all outwash deposits, the discharging water was received by the Chehalis valley largely on the east or west side of the Black Hills. Extensive tracts are rendered as worthless for agriculture by these outwash plains as though in an arid country. For example, the road through the sparse forest extending from Lake Nahwatzel to Shelton crosses but one stream bed and this carries water only during the very rainy winters and no valley has been cut. As already noted, the moraine across the low area between the Black Hills and the Olympic foothills has been partially buried in the flood of gravel and its relief much reduced.

The question of contribution from valley glaciers in the bordering Cascades and Olympics cannot be adequately treated in our present state of knowledge. Valley glaciers in these mountains on the Soundward slopes debouched into a great mass practically filling the depression from rim to rim. That they would perform much erosion under such conditions is not to be expected. Willis has found the till sheet of a Cascade piedmont glacier on the eastern part of the Tacoma quadrangle, a part of which is indicated on the accompanying map. The relative insignificance of the Skokomish glacier whose lower extremity occupied the basin of Lake Cushman has been shown. No evidence has yet been found that tributary glaciers north of these two produced any perceptible

effect on the mass of the course of the great Vashon glacier, whose volume and thickness was of course greater northward.

Definite recessional moraines are yet unknown in the Puget Sound country. Between the terminal moraine and the southern arms of the Sound are occasional moraine hills and ridges which will probably resolve themselves into linear arrangement when carefully studied and will constitute recessional moraine deposits. But in the larger area of longitudinally ridged drift among the arms of the Sound, there is little of morainic origin beyond scattered lodge moraine hillocks in the valleys.

Russell[1] first noted that there are two till sheets in Puget Sound basin, recording two glaciations. Willis[2] has named these the Admiralty and Vashon, with the latter of which we have had to do. The frequently weathered condition of the Admiralty till or of its superposed outwash has been pointed out by Willis as evidence of long exposure before the Vashon glaciation. The freshness and slight erosion of the Vashon till sheet and moraine evince an age comparable to that of the Wisconsin drift.

A notable feature of the Puget Sound glaciation, shown by the failure of constant careful search to find older till beyond the moraine, is that the last glaciation of the region, doubtless Wisconsin in age, was the most extensive. Frequent incorporation of residual soil in the Vashon till is the best evidence which might be secured, in the absence of deep sections, that it overlies areas never previously glaciated.

[1] Bailey Willis, "Drift Phenomena of Puget Sound," *Bull. Geol. Soc. Am.*, IX.

[2] Willis and Smith, "Tacoma Folio No. 54," *U.S. Geol. Survey.*

Editorial

THE SEEDING OF WORLDS

As a sort of initiation stunt precedent to admission into the fraternity of agencies of good and regular standing, every new agent that is brought into view by the ongoings of science is likely to be set to the task of solving some large part of the outstanding puzzles that still vex the wise men of our craft. "Light pressure" is one of the latest novitiates on trial, and has been set to the stunt of seeding the habitable but not inhabited worlds by spores from some previous spore-growing world. The seeding of the first world is mercifully not made a part of the stunt. So too, to help out the novitiate somewhat, the hazards of the cold of space are mitigated by bringing to bear certain novel tenets about endurance of extreme cold, and by cutting the time by the great speed of the trip from world to world under the new pressure. The stunt still remains a stiff one and is interesting, but the fraternity seems to be missing the best part, the getting home to the new world; no doubt because it is so far off.

The start of the spore from the spore-growing planet is not without its little difficulties; for the seed, be it even so light as the airy fluff of the puffball, must yet not only get out to the very top of the air, but it must be pushed off by the pressure of the light at a speed of some 5 or 6 miles a second to be able to get away from the pull of the parent world, if that world be a body like our familiar acquaintance, the earth. A Krakatoan blast, however, can no doubt give the spore a lift, if need be. But the getting away is not the interesting part of the stunt; it is the landing.

If "light pressure" has once pushed the spore out of the clutches of the parent world and got it well under way, all is likely to go well till the bounds of the sun's sphere of control are reached and the border of the domain of the other sun is entered, for that sun is likely to push back as much as the parent sun pushed out. In matters of this sort one sun seems unwilling to be the dumping-

ground of another sun. So now, between the opposing pushes of the rival suns, comes the real trial of skill or luck in landing the spore. If the seed be duly planted, the fraternity door should surely open for the candidate *magna cum laude*.

On leaving the domain of the old sun and entering the field of new suns, care or luck in hitting on a sun that shines less bright than the one that has pushed the spore out is surely needed, or else the back-push of the brighter sun will grow in time to be stronger than the on-push of the old sun and the spore will be stopped or turned aside. If someone churlishly remarks that the seeding of new worlds can thus only go down the scale of solar radiance, let that pass; it is enough to seed at long distance any world.

Hitting upon a sun of duly lesser radiance, the spore must shoot straight for it, quite straight, center to center, for if the backward push of the sun ahead is a little awry at the front, the spore will be pushed aside and out of line, and once off the line it will be turned more and more away and surely go astray. Nor must the chosen sun move out of line while the spore is coming toward it, or else the front push will surely turn the spore away. No sun must be hit upon but one that will stand still, if such there be, while the spore is getting home to the new planet, or, if no sun stands still, a sun must be hit upon that is coming toward or else is going straight away from the advancing seed.

All ill luck in hitting the right path or in hitting on a sun moving straight toward or straight away from the speeding spore once duly escaped, the larger perils are past, but not all; there are perils of side pushes. In hitting upon a star of proper weakness of radiance and coming or going or standing still duly, the spore may chance to pass some brighter star off the line and its side push may turn the spore off its course; or stars may be thicker or brighter on one side or another and the spore be put off its course by their united pushes. Where, then, it may again be churlishly asked, is a spore to go if all the suns push it away? Well, it is not a part of this stunt to chase up lost spores; still, there are "dark lanes" and "coal sacs" and "openings" leading out into room "outside the universe."

Then too there are perils of planets as well as perils of suns.

As the spore pushes down against the radiance of the defendant sun, one of whose planets, near enough to it to keep duly warm, is to be seeded for a new life kingdom, a planet just at the right spot must be hit upon. Luck must here stand the spore in good stead, for the chances are not the best. If the planets of the chosen sun circle round it cross-ways, in any but the minutest degree, they will never be in the center-to-center line of the spore's path, for, as we have seen, the spore must keep true to line or the backward push of the light pressure in front, striking aslant, will turn the spore off. There is a chance indeed that a spore will get down to just the right point and then be turned off just so as to strike a planet that is off line, but it is not a chance to stake much on. To have any fair chance of getting home to a planet while the spore keeps straight on toward the repellent sun, under the superior inertia it got from the sun it left, the planet must circle round the sun in a path that cuts this line.

And then, too, the planet must be there at just the right time. The spore must no doubt cross the spot in the wink of an eye, or less, and the new world must be there on exact time if it is to be seeded. It is not unfair that it should be made to be there on time as its part of the stunt, for the spore has come far to do its part.

Now if all has gone well thus far there is only the landing left. If the spore was pushed out from the old sun too fast, it may plunge so swiftly into the air of the new world as to strike fire and burn or brown itself fatally. But if pushed out just right at the start and pushed back just right on the road, it may land with little more than the speed forced by the pull of the new earth, a matter of a few miles a second, it may be.

When the speed of the spore is stopped and it floats in the outer air of the new earth it may perchance from being too hot come quickly to be too cold and the change from warmth to chill may try its salamandrine powers before it sinks to the warm air low down or to the ground in which it is to grow.

The luck of the spore must stay by it a little farther in its lighting. All may be lost if it falls on polar snow, or mountain peak, or desert plain, or perchance in the ocean midst, if it is not

a salt-water spore. It must fall in a spot where it can grow, where its family, as it comes to have one, may live and multiply and grow into a kingdom, for if it fails in this last, the kingdom will not be won.

The stunt may be perilous; but it is easy to see how easy it is to do if done just right. Light is the great foster-farmer of the earth, the truly great farmer; and we now see how clearly and truly "light pressure" is the long-distance seed-planter of the worlds. T. C. C.

ARTESIAN WATERS OF ARGENTINA

The climate of a part of Argentina is semi-arid, and the geological formations which are regarded as Quaternary and Later Tertiary are, in the western and central districts of the country, saline to a degree which indicates prolonged duration of aridity. The region of the Pampas which covers the province of Buenos Aires and stretches northward west of the Parana does not exhibit this characteristic, having apparently long enjoyed a more humid climate, as it does now. The foothills of the Andes are also well watered. But with the exception of these last-named regions, a great part of the country suffers from lack of good water. This condition may, however, be in some measure relieved by proper development of artesian supplies. Many wells have been sunk already, but without adequate geological investigation. In the Pampas, water is found at a general depth of 20 meters more or less, and is pumped to the surface by windmills. It may be said that the development of the livestock industry of Argentina would be impossible were it not for this supply which comes from eolian, alluvial deposits of Quaternary and Tertiary age. A different geological condition exists from the Rio Colorado southward in what may be best described as northern Patagonia. In that region there are local elevations occupying a middle position between the Atlantic and Pacific, composed of granites and older rocks possibly of Paleozoic age, and rising to altitudes of 300 to 1,000 meters. These mountains are not represented upon any map and their distribution is not known, but they have been described by Moreno and other explorers. Upon their flanks there

is an extensive formation of gray sandstone which attains a thickness of several hundred feet and is very porous. It slopes gently toward the Atlantic and pure water flows from it in outcrops near the coast. The head of water in these strata is unknown. Farther south in Patagonia the central sierra is replaced by plateau country and in Comodoro Rivadavia, in latitude 46 near the coast, wells which were sunk by the government in search of water developed petroleum. There is a large area in this region in which the geologic structure and the possibilities of artesian water need to be developed. In the great plains east of the Andes there are glacial deposits which may furnish superficial supplies like those of the Dakotas, and the marine Tertiary and Mesozoic strata afford conditions not unlike those of southern California. Here as well as in the valleys among the spurs of the Andes from Patagonia to Bolivia the geological structure is complicated and the problem of artesian water is one of peculiar difficulty as well as of great interest.

Our present knowledge of these conditions rests upon reconnaissance work and the stratigraphic and paleontologic observations of the Geological Survey of Argentina. No work based upon topographic maps and systematic structure has as yet been undertaken. The problem is therefore one whose elements are as yet to be developed. The Argentine government is using every means to encourage settlement and development of the rich agricultural regions which lie in the zone of sufficient rainfall east of the Andes, and also the vast grazing district of Patagonia. In order to afford ready communication it is building railroads at great national expense and operating them. The need of pure water for locomotive use as well as for other purposes has thus been made critically evident, and the minister of public works, Señor Ramos Mexia, has adopted a plan for making surveys for the determination of artesian water conditions along the lines of national railways. He contemplates topographical and geological surveys of a character similar to those executed by the United States Geological Survey, from which he derived the initial suggestion. He last summer applied to the United States government for the services of a geologist and such assistants as he might need, and our govern-

ment has responded cordially to that request. Mr. Bailey Willis has accordingly entered into a contract for the term of two years, to execute topographical and geological surveys for the specific purpose of ascertaining artesian water possibilities in those districts which the minister may designate. With him are associated Mr. Chester W. Washburne of the United States Survey, Mr. J. R. Pemberton of Stanford University, and Mr. Wellington D. Jones of the University of Chicago, as geologists, and Mr. C. L. Nelson and Mr. W. B. Lewis as topographers, and the party has recently sailed for Argentina to enter upon the work. While these surveys have a specific purpose, their possibilities of usefulness in developing the natural resources and encouraging settlement in the regions surveyed will not be overlooked, and the work will be founded on those scientific studies upon which alone practical conclusions can safely rest. Thus it is hoped that a definite contribution to knowledge in geography and geology may be made.

It is desirable to point out that the Argentine government has a geological survey which has been in existence since 1903 in its present organization and which dates back half a century as a bureau of mines. It is under the direction of Señor E. M. Hermitte, who is assisted by Messrs. Bodenbender, Keidel, and Schiller, three German geologists who have done excellent stratigraphic and paleontologic work, particularly in districts of the central Argentine Andes. They have unfortunately not been supplied with maps. The established Bureau of Mines, Geology, and Hydrology is under the Minister of Agriculture. The surveys which are about to be made are undertaken by the Minister of Public Works. The two operations are thus officially distinct, but it is hoped and anticipated that they may be mutually helpful.

B. W.

Petrographical Abstracts and Reviews

Edited by ALBERT JOHANNSEN[1]

Benedicks, Carl, and Tenow, Olof. "A Simple Method for Photographing Large Preparations in Polarized Light," *Bull. Geol. Inst. Univ. Upsala*, IX (1910), 21–23.

For the description of the comparatively simple apparatus used, reference must be made to the original paper.

W. T. Schaller

Bowles, Oliver. *Tables for the Determination of Common Rocks.* New York: Van Nostrand, 1910. 16mo, pp. 64+84 advs. 50 cents net.

Cui bono?

Written, as this book is, for "beginners in lithology," it is especially unfortunate that the author's statements are often very misleading. For example, in the chapter on "Rock Classification" the statement is made that "igneous rocks . . . . represent the original solid crust of the earth," and that "sediments . . . . are but modifications, or reconstructed phases, of this primary type." A short chapter on the determination of the rock-forming minerals is followed by 18 pages of tables for the determination of the common rocks. The methods of identification are given in extremely brief form, but would a "beginner," or anyone else, classify andesite, quartz porphyry, felsite, or phonolite as "ashy, and often with a few phenocrysts, mostly cellular"?

The book ends with a ten-page chapter on "Building Stones" and a seven-page glossary. The volume is No. 125 of Van Nostrand's Science Series and is uniform in size and binding with the remainder of the set.

Albert Johannsen

Bowman, H. L., and Clarke, H. E. "On the Structure and Composition of the Chandakapur Meteoric Stone," *Min. Mag.*, XV (1910), 350–76. Pls. 2, and analyses.

A full description, with extensive chemical work, on a large piece of the meteoric stone which fell at or near Chandakapur, India, on June 6,

[1] Authors' abstracts will be welcomed and may be sent to Albert Johannsen, Walker Geological Museum, The University of Chicago, Chicago, Ill.

1838. It is an intermediate chondrite, with olivine and pyroxene as the most important constituents. Metallic iron and nickel form nearly 6 per cent, and combined iron and nickel, 5 per cent.

W. T. SCHALLER

DALE, T. NELSON. "The Cambrian Conglomerate of Ripton in Vermont," *Am. Jour. Sci.*, XXX (1910), 267–70. Figs. 3.

A conglomerate formed of pre-Cambrian pebbles generally held together in a highly metamorphosed "muscovite-quartz schist with more or less magnetite." The pebbles are a beach formation and are of local origin as is shown by their large size and by their similarity to adjacent rocks.

ALBERT JOHANNSEN

DUPARC, WUNDER, AND SABOT. "Les minéraux des pegmatites des environs d'Antsirabé à Madagascar," *Mém. Soc. Phys. et d'Hist. Nat. Genève*, XXXVI (1910), fasc. 3, 283–410.

The geology of Madagascar is briefly described and then, in detail, are described the rocks around Antsirabé. These include basalts, granites, quartz diorites, pegmatites, cipolines, quartzites, and mica schists. The localities of the pegmatites are then given in detail. The pegmatites occur chiefly in the cipoline and are formed principally of microcline and quartz, or plagioclase (near albite) and quartz. Mica, tourmaline, beryl, garnet, and pyroxene are also present.

In the second part of the paper are mineralogical descriptions of microcline, amazonite, lepidolite, lithionite (zinnwaldite), beryl (rose-pink and aquamarine), tourmaline, spodumene, spessartite, garnet, and cordierite from the mica schist of Mount Ibity.

W. T. SCHALLER

GRABHAM, G. W. "An Improved Form of Petrological Microscope; with Some General Notes on the Illumination of Microscopic Objects," *Min. Mag.*, XV (1910), 335–49. Figs. 5; pl. 1.

Suggests several improvements on a Dick microscope, namely, a better adjustment for the condenser system, a triple nose-piece, iris diaphragm, and a slot for introducing screens below the stage. The graduated circle is placed below the ocular. Several other suggested improvements have already been used on other microscopes. Several

pages are devoted to the "Illumination of the Object." An explanation of the "white-line effect" (Becke's line) is given for parallel light where the contact plane of the two minerals in question is at various inclinations.

W. T. Schaller

Grayson, H. J. "Modern Improvements in Rock Section Cutting Apparatus," *Proc. Roy. Soc. Victoria*, XXIII (1910), 65–81. Pls. 4.

Describes an apparatus, constructed for the University of Melbourne, with which the writer is able to slice, grind, and mount thin sections of about an inch in diameter and of a thickness of less than 0.001 inch, from rocks of the hardness of granite, in not more than ten minutes. Using two cuts with a diamond saw for each slide, the cost per section is about one shilling.

A mechanical device for doing the rough grinding would be an improvement. With a number of laps running simultaneously, the greater length of time required for each section would be no drawback, and there would be a considerable reduction in cost since it would not be necessary to use diamond dust.

Albert Johannsen

Grout, Frank F. "The Composition of Some Minnesota Rocks and Minerals," *Science*, XXXII (1910), 312–15.

A preliminary statement regarding the composition of certain Minnesota rocks. There are given analyses of seven rocks and fourteen minerals.

Two or three types of granite occur in laccoliths of considerable size in the Keewatin schists and are considered by the author as probably of that age. These granites are intersected by diabase, quartz diabase, and quartz porphyry dikes, and there occur a few masses of gabbro. Most of the Minnesota effusive rocks belong to three types of diabase which, chemically, are classed as Hessose, Bandose, and Auvergnose.

The country rock was tested for copper. The common theory of the origin of the Lake Superior copper deposits is that of lateral secretion from the diabases. In the present tests it was found that copper occurs in all the main types of rock, and, so far as could be judged from the ten samples tested, the fresher the rock, the larger the amount of copper. It varied in amount from 0.029 to 0.012 per cent.

Albert Johannsen

Högbom, A. G. "Ueber einen Eisenmeteorit von Muonionalusta im nördlichsten Schweden," *Bull. Geol. Inst. Univ. Upsala*, IX (1910), 229–38. Pl. 1.

This is a description of the first iron meteorite found in Sweden. The essential constituents are the iron-nickel kamazite, taenite, and plessite. Troilite and daubréelite form a minor part. Chemically, the meteorite contains 91 per cent Fe and 8 per cent Ni.

W. T. Schaller

De Lapparent, Jacques. "Les gabbros et diorites de Saint-Quay-Portrieux et leur liaison avec les pegmatites qui les traversent," *Bull. de la Soc. Française de Minéralogie*, XXXIII (1910), 254–70.

Near Saint-Quay-Portrieux on the coast of Brittany, intrusive in mica schists, there is a mass of rather coarse hypersthene-gabbro with a periphery of dioritic facies. Both gabbro and diorite contain inclusions of a finer-grained hypersthene-bearing rock with the structure of beerbachite. These rocks are cut by dikes of aplite essentially composed of labradorite and quartz. The diorite and the marginal, but not the central, part of the gabbro are cut also by small dikes of pegmatite composed essentially of microcline, albite, quartz, and a little biotite, with local muscovite and tourmaline. The albite has crystallized before the microcline.

The principal types are represented by five analyses.

The microscope shows the hypersthene of the gabbro in process of replacement by a mixture of biotite and quartz, and the augite more or less uralitized. In the peripheral "diorite" both alterations are much more advanced; the augite is almost completely uralitized, and the hypersthene wholly replaced by biotite and quartz. The author ascribes these changes to the agency of the pegmatite and believes them to have been effected before the gabbro was fully consolidated. He considers for reasons not fully stated that the first phase was the production of soda-lime feldspar by the reaction with the femic magma of siliceous alkaline vapors, rich at first in soda. He supposes the vapors subsequently to have become more abundant and richer in potash, water, and boric acid. The quartz and biotite, it is pointed out, would be formed by combination of the constituents of hypersthene with those of potash-feldspar; there is evidence that this reaction took place in the central gabbro before the hypersthene was completely crystallized, and in the

peripheral "diorite" even before that mineral was individualized. The transformation of augite to amphibole, accompanied by crystallization of quartz, is considered to have been the final reaction, effected mainly by the water and boric acid in which the vapors became relatively richer as the consolidation of alkalies and silica progressed.

M. de Lapparent believes that the action of the kind here described is common, and especially, that it has occurred in certain American rocks.

F. C. Calkins

Michel-Lévy, Albert. "Les terrains primaires du Morvan et de la Loire," chap. v, "Etude pétrographique et chimique des roches éruptives du faisceau synclinal du Morvan," *Bulletin des Services de la Carte Géologique de la France*, XVIII (1908), 209–68.

The area described is part of the central plateau of France, made classic by the thorough studies of the elder Michel-Lévy and others. Its rocks furnished the basis for some important principles of the science, and some of them are illustrated in the beautiful plates that accompany the "Minéralogie Micrographique." A historical summary and bibliography relating to these early researches is given in the present work. The petrographic descriptions in this work are brief; its principal contribution is a series of chemical analyses, twenty-five in number, which are used to show the position of each rock in the American quantitative classification and in that of Michel-Lévy.

The principal deep-seated rock is a coarsely porphyritic granite (alaskose) with potash distinctly more abundant than soda. The phenocrysts of potash feldspar are the last constituents to crystallize. This rock passes into microgranite and "microgranulite." Associated diorite (hessose) and amphibolitic porphyries (andose and tonalose) are said to have been formed by digestion of calcareous sediments in the granite. No full argument in support of this assertion is made, the author evidently considering that previous work by Michel-Lévy and Lacroix has established the frequent occurrence of this type of endomorphism.

The exomorphic action of the granite has affected limestones, shales, sandstones, and conglomerates. The most interesting result of the metamorphism has been the introduction of albite and orthoclase in all these rocks, especially in close proximity to contacts, by "alkaline fumaroles" from the magma.

The volcanic rocks—of Paleozoic age—comprise: (1) Upper Devo-

nian albitophyres, in the form of breccia and tuffs, with phenocrysts of albite, orthoclase, microperthite, and rarely of brown hornblende, in a groundmass of albite microlites. In the quantitative system these belong to dacose, andose, and subrang 5 of dacose, not named nor even represented by analyses when that system was published. (2) Carboniferous orthophyres, also in the form of tuffs and breccias. The phenocrysts are of orthoclase, albite, and in some cases anorthoclase; the groundmasses where crystalline are of orthoclase microlites and poikilitic quartz; some are glassy and perlitic. They belong to alaskose, liparose, and the unnamed subrang I (perpotassic) of alaskose. (3) "Microgranulitic tuffs," consisting of fragments of andesine, bipyramidal quartz, and biotite in a chalcedonic cement. These are water laid and apparently not of purely volcanic material. They belong to toscanose and are more limy than the albitophyres. (4) "Microgranulites." Some of the rocks thus designated are hypabyssal, others, passing into "porphyre pétrosilicieux," are thick, devitrified rhyolitic flows. An analysis of the hypabyssal rock is that of a toscanose, while the two specimens analyzed of the extrusive rock are alaskose and liparose. (5) Lamprophyres. These also occur partly as thin dikes and partly as flows. The dike rocks have phenocrysts of biotite and pyroxene in a groundmass of orthoclase, plagioclase, and biotite; the lavas have phenocrysts of olivine, augite, and sometimes hypersthene, in a groundmass of plagioclase, orthoclase, and sometimes biotite. In the quantitative classification, they are harzose, shoshonose, and auruncose. Chemically both extrusive and intrusive "lamprophyres" are characterized by richness in potash, resembling in this respect the porphyritic granite from which they are supposed to be differentiates.

The author summarizes the chemical data by estimating the average composition of each group of rocks and of all the rocks together excepting the diorites, albitophyres, and granulites. With these exceptions, all are markedly consanguineous, and the general average composition has in the scheme of Michel-Lévy the same "magmatic parameters" as the granite supposed to be the "mother-rock."

The albitophyres, by their richness in soda, are in remarkable contrast to the other rocks, in which dominance of potash is general. It is a striking circumstance that names are wanting in our quantitative classification for two of the albitophyres because of their unusual richness in soda, and for two other rocks—an orthophyre and a lamprophyre—because of their unusual richness in potash.

F. C. Calkins

NORDENSKJÖLD, IVAR. "Der Pegmatit von Ytterby," *Bull. Geol. Inst. Univ. Upsala*, IX (1910), 183–228.

Numerous lenses of pegmatite occur at Ytterby on Resarö Island, about 20 km. E.N.E. of Stockholm. Some of the pegmatites are found between diorite and gneiss, and others occur in hornblende gneiss. A zonal structure is noticeable, the pegmatites being finest grained near the contact. Large masses of pure red potash feldspar (microcline perthite), white plagioclase (oligoclase), and massive quartz are found in the center of the lenses. The potash feldspar is especially valuable and the minerals are mined and used in the manufacture of porcelain. Graphic granite is also abundant. Of the micas, a dark biotite is more common than muscovite. It is often chloritized and it is with this altered mica that the rare minerals fergusonite, gadolinite, etc., are found. The descriptions of the rare earth minerals, largely historical, include also yttrotantalite, allanite, xenotime, and altered zircon.

W. T. SCHALLER

RASTALL, R. H. "The Skiddaw Granite and Its Metamorphism," *Quart. Jour. Geol. Soc.* (London), LXVI (1910), 116–41. Map.

A study of the alteration produced in the sedimentary rocks of the Skiddavian Series by the intrusion of an alkali granite commonly known as the Skiddaw granite. The metamorphism extends over a considerable area, although the outcrops of granite are limited to three of rather small extent which the author supposes to be part of a large mass continuous beneath the surface. From the repetition of the same sequence of rock-types in reverse order, it appears that the structure of the region is that of a complicated anticline or syncline, the former being most probable. The position of the granite mass suggests that it was intruded along the main axis of this anticlinorium, and the author believes its injection closely followed or even accompanied the folding. If this is true, here is an example of a direct relation between intrusion and folding. The chief minerals produced by the metamorphism were cordierite, andalusite, biotite, and muscovite, with garnet and staurolite near the granite contact. The absence of cyanite and sillimanite indicates that the rocks were never subjected to a very high temperature, and all the evidence points to the maintenance of a moderate temperature for a long period of time, such as would result from the intrusion, under a thick cover, of an igneous mass not very highly heated.

ALBERT JOHANNSEN

SCHALLER, W. T. "Axinit von Californien," *Zeitschr. Kryst.*, XLVIII (1910), 148.

A chemical and crystallographic description. The conclusion is reached that axinite is composed of the two isomorphous minerals, ferroaxinite, $Al_2B\ H\ Ca_2\ Fe\ Si_4\ O_{16}$, and manganoaxinite, $Al_2\ B\ H\ Ca_2\ Mn\ Si_4\ O_{16}$.

AUTHOR'S ABSTRACT

SMITH, G. F. HERBERT. "A Camera-lucida Attachment for the Goniometer," *Min. Mag.*, XV (1910), 388–89. Fig. 1.

The camera lucida is used for the representation of "light figures" on imperfect crystals with rounded or striated faces, and for the delineation of small crystals.

W. T. SCHALLER

WINCHELL, ALEXANDER N. "Use of 'Ophitic' and Related Terms in Petrography," *Bull. Geol. Soc. America*, XX (1910), 661–67.

A history of the term ophitic which was introduced in the literature by Michel-Lévy in 1877. Originally defined as a texture characterized by feldspars, peculiarly grouped, inclosing more recent diallage or augite, it is at the present time used either in the original sense or applied only to those textures in which the feldspar is inclosed by large anhedra of pyroxene.

The writer believes the term should be applied to all rocks having plagioclase in lath-shaped crystals which were formed before the ferromagnesian constituents, and suggests the term "poikilophitic" for that texture which is at once ophitic and poikilitic.

Alfred C. Lane, "Winchell on Ophitic Texture," *Science*, XXXII (1910), 513, says: "It seems to me that . . . . a pyroxenic matrix is an essential part of the idea of the ophites. I am, however, quite willing to give up the idea that the augite must necessarily be altogether in larger grains than the feldspar."

ALBERT JOHANNSEN

Reviews

Die Weltkarten-Konferenz in London im November, 1909. By ALBRECHT PENCK. *Zeitschrift der Gesellschaft für Erdkunde.* Berlin, 1910. Pp. 114–27.

This paper states briefly what was done at the international conference held in London in November, 1909, looking toward a map of the world on a uniform scale of 1:1,000,000. Starting with the inception of the idea at the Bern meeting of the International Geographic Congress in 1892, past efforts which have led to the present stage are reviewed. The main features of the resolutions adopted by the London Conference were:

That all nations participate in a world map of 1:1,000,000 scale with uniform symbols; that the size of the sheets be uniform; that each sheet cover 4 degrees of latitude and 6 degrees of longitude (except that north of 60° N. lat. and south of 60° S. lat. two or more sheets of the same zone may be united); that each sheet have an international designation, as North B 12; that the latitude of the sheets be represented on each side of the equator to latitude 88° by the letters A to V, and distinguished as "North" or "South"; that each polar chart be designated Z; that the longitude in units of 6° be represented by the numbers from 1 to 60, the count beginning 180° from Greenwich and proceeding from west to east; that in projection, the meridians be straight lines, and the parallels be arcs of which the middle points lie on the prolongation of the middle meridian; that the elevation of the land be represented by a color scale using 100-meter contour division lines for regions of ordinary relief.

In addition to these leading features the recommendations treat of a great many details upon which decisions were necessary in order to secure uniformity of results in the completed map.

While further consideration and conference will be necessary to determine who shall make the different maps, this conference has prepared the way for the adoption at an early date of a common plan of operations. This important enterprise now seems to be fully under way.

R. T. C.

"Prospecting in the North." By HORACE V. WINCHELL. *The Mining Magazine,* Vol. III, No. 6, p. 436. December, 1910.

The writer compares the sulphide ore deposits of the western part of the United States and Mexico with those of British Columbia and Alaska and notes the differences in the operations of the processes of superficial alteration and secondary enrichment in the different latitudes. In the more northern deposits the metals have not migrated in cold solutions so extensively, because the colder climatic conditions are less favorable. Further, the secondary ores, where found, have generally been planed off by ice erosion.

Since glacial times, at some places, a kind of secondary sulphide enrichment has taken place at the very surface, but generally this amounts to little more than a veneer or varnish on the lower-grade material. His conclusions, applied to deposits of sulphide ores of copper, silver, lead, and to some extent, of gold, are: "(1) Boreal regions seldom contain rich and extensive deposits of secondary ore. (2) The surface appearance is often deceptive, and if the ore is high grade, sudden decrease in value may be expected at limited depth. (3) Where large deposits of *primary ore* are found in glaciated regions, these are likely to extend downward." In the temperate zone, "(1) Deep superficial alteration and complete oxidation of vein-matter is a common phenomenon in warm countries and is indicative of good ore below; (2) In general, ore deposits are more abundant in the warm and temperate zones; and (3) They are not so likely to terminate suddenly or change rapidly in depth."

W. H. E.

Geological and Archaeological Notes on Orangia. By J. P. JOHNSON. London: Longmans, Green & Co., 1910. Pp. 99.

This volume contains chapters on Stratigraphy, Kimberlite Dikes and Pipes, Diamond Mines, and Superficial Deposits and Pans.

Almost the whole surface is made up of nearly horizontal beds belonging to the Karoo System, with comparatively small outcrops of older formations along the Vaal River. In the area best exposed these older beds dip away from a central core of granite and are overlain unconformably by the Karoo.

The lowest of the Karoo beds is the Dwyka series, which is described as a band of bowlder shale. The underlying rocks wherever exposed are polished and present the characteristic contours of a glaciated country.

The evidence of the striations indicates a general movement of the ice from northeast to southwest. The Ecca or Beaufort series, consisting of fifteen hundred feet of sandstone and shale, occupies most of the surface, while the Stormberg series is found along the eastern border.

The whole area of Orangia has been intruded by a network of basic dikes and sills of nearly the same composition, and at a later date by the veinlike pipes and dikes of the diamond-bearing rock. This rock, which is known as Kimberlite, has a wide distribution in Orangia, filling both narrow fissures and vents or pipes. Its nature is as yet imperfectly known, some occurrences giving the impression of a consolidated igneous rock, others being apparently purely fragmental. The author thinks that the typical fissure Kimberlite is a magmatic intrusion, and that the pipes were originally filled, perhaps on more than one occasion, with a magma, which, except near the depth of origin, must have had a very low temperature for an igneous extrusion and which, after solidification, was smashed up by frequently repeated explosions.

E. R. L.

The Slates of Arkansas. By A. H. PURDUE, with a Bibliography of the Geology of Arkansas by J. C. BRANNER. Geological Survey of Arkansas, 1909. Pp. 164.

The part of this volume which is of greatest general interest is chap. iii, which deals with the geology of the slate area. This area includes the part of the Ouachita Mountains from Little Rock westward for about one hundred miles. The sedimentary rocks of known age are of Ordovician and Carboniferous (Pennsylvanian) age, with rocks of unknown age both above and below the Ordovician.

Above the rocks of known Ordovician age is a group of three formations of which the well-known Arkansas novaculite is the middle member. In a former publication of the Survey these were all classed as Ordovician, but the author finds no proof of this and thinks that they may be Ordovician, Silurian, or Carboniferous.

The region is one of intense folding, and thrust faulting is quite common.

E. R. L.

Geological Survey of Georgia. Bull. No. 23, "Mineral Resources." By S. W. McCALLIE, State Geologist. Pp. 208.

The introductory chapter on the geology of the state is brief and presents no new facts. The descriptions of the mineral deposits are arranged alphabetically, the general distribution, the mode of occur-

rence, the history of development and values being treated for each type of deposit. In most cases no attempt is made to inquire into the genesis of the deposits.

In a work of this nature whose value is chiefly statistical one would expect a general summary and table showing the relative importance and value of the various deposits, but none is found in this volume. Of the ores of the state, those of iron are by far the most important. In 1907 they were mined to the value of over $800,000. E. R. L.

The Mining Industry in North Carolina during 1907 with Special Report on the Mineral Waters. By JOSEPH HYDE PRATT. North Carolina Geological and Economic Survey, Economic Paper No. 15. Pp. 176.

The most important part of this paper is a report on the Gold Hill Copper District by F. B. Laney (pp. 20–55). This district is located in the south-central part of the state just west of the Yadkin River. The rocks are slates and igneous rocks of various kinds, and of different periods of intrusion. The ores are (1) auriferous pyrite and chalcopyrite in a quartz gangue and (2) slightly auriferous bornite and chalcocite in a quartz epidote gangue. No attempt is made to correlate the period or periods of ore deposition with a period of igneous activity or to determine the age of the ores.

The remainder of the paper is chiefly statistical.

E. R. L.

Paleontology of the Coalinga District, Fresno and Kings Counties, California. By RALPH ARNOLD (U.S. Geol. Surv. Bull. 396). Pp. 101 and plates 30.

The district forms a strip roughly fifty miles long by fifteen miles wide along the border between the Coast ranges and the San Joaquin valley. The eastern slope of the mountains is formed by a great thickness of strata dipping toward the valley, successively younger formations being exposed to the east. The rocks of the district range in age from the Franciscan formation, which is probably Jurassic, to rocks of recent age, with an unconformity at the base of almost every formation. A description of the formations with faunal lists is followed by description of forms from the Tejon formation (Eocene), the Vaqueros, the Jacalitos, and the Etchegoin formations (Miocene), and the Tulare formation (Freshwater Pliocene).

E. R. L.

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CERTAIN PHASES OF GLACIAL EROSION

THOMAS C. CHAMBERLIN AND ROLLIN T. CHAMBERLIN
The University of Chicago

Oscillation, more or less rhythmic, seems to be a phenomenon of the intellectual, as well as of the physical world. The doctrine of glacial erosion has its ups and downs in quite typical undulatory fashion. It seems that even individuals at times ride on the crest of the wave of advocacy and at other times sink into the hollows of doubt. These moods are apt so to distribute themselves that while some workers are on the crest others are in the trough. The crest-riders have recently been much the most in view, but just now voices from the hollows of doubt are heard. The president of the British Association for the Advancement of Science, speaking from official vantage ground, voices a cautious skepticism as to the glacial parentage of certain kinds of configurations that are held by others to be the erosive offspring of glaciers.[1] Professor Garwood goes beyond the measured skepticism of Dr. Bonney and gives a critical analysis of his grounds of doubt and laudably matches his destructive criticism with constructive interpretations. In these interpretations, he marshals topographic phenomena in support of the view that *protection*[2] is the characteristic effect of glaciers rather than erosion.

[1] T. G. Bonney, Presidential Address before B.A.A.S. (Sheffield, 1910), *Science*, XXXII (1910), 321–36, 353–63.

[2] E. J. Garwood, "Features of Alpine Scenery Due to Glacial Protection," *Geog. Jour.* (September, 1910), pp. 310–39.

So, too, among those who believe in the efficiency of glacial erosion, there has long been some doubt as to the truth, or at least as to the adequacy, of some of the processes to which the erosion has been attributed.

It seems worth while, therefore, to add to the growing mass of matter some notes suggested by phenomena recently seen by us, without presuming that much is new either in the observations or in the suggestions.

I. THE CRITICAL STAGE FROM WHICH CERTAIN EROSION TYPES START

It has seemed to us advantageous to study the initial stages of erosion to see, if possible, precisely what action gives the start to the type of erosion which thereafter controls the configuration, for it is the initial turn that most delicately measures the balance between the opposing tendencies.

The contours that spring from ordinary wear and weathering are well known and may be restored from remnants when the greater part has been lost. Even when there has been no change in the agent and only a slight change in its mode of action, the old configuration can be distinguished from the new; as, for familiar example, the remnants of a peneplain are commonly made out with confidence after most of the plain has been cut away by the rejuvenation of the very drainage system that formed it. Much more clearly can remnants of contours be rebuilt into their originals when some *new* agency intervenes, especially a new agency whose habit of sculpture is distinctively at variance with that of the previous agency.

As surface configurations are traced from regions dominated wholly by ordinary wear and weathering into regions that have been affected by local glaciation, it is usual to find the lower slopes of the unglaciated region and, in the main, the brows and tops of its hills and higher elevations, up to a certain limit, marked by contours of the familiar wear-and-weather type whose interpretation is clear and whose restoration, when mutilated, may be made with great confidence. As such contours are traced into higher latitudes or higher altitudes where local glaciation has entered

sparsely as a modifying factor, it is usual to find the flowing contours of the wear-and-weather type replaced in certain spots by a type that may be said to be unconformable to the prevalent one, a type in which concavity replaces convexity, a type in which the surface has been broadly scooped out locally rather than rounded off generally or narrowly incised. The broad scoop-like mode of excavation, as distinguished from the gully-form mode of narrow incision, is held to be distinctive in that it implies an agency that deployed its effects laterally rather than one which concentrated its action on axial lines. This, it is to be noted by way of precaution, is a distinction that applies chiefly to the initial stage of the two modes of erosion. They remain distinguished throughout but are not so declaredly diverse in later stages.

The lodgment of snow, which is the primary factor in glacial work and determines its initial deployment, is controlled by the wind to an exceptional degree, and wind action is chiefly horizontal in its effects and is thus distinguished from rainfall and run-off, whose dominant actions are vertical. While the very first phases of this difference of action are not very important in themselves, they are believed to be significant as the initial factors in the localization as well as the deployment of the two classes of erosion.

The relative locations of greatest rain-work and greatest snow-work respectively.—Precipitation is intimately dependent on the ascent of air so well laden with moisture that it reaches saturation by reason of the expansion and cooling caused by the ascent. It is for this reason that the ascent of moist air caused by rising over the windward face of any marked relief of the topography determines precipitation on or near that face. As is well known the windward sides of mountain chains thus receive more precipitation than the leeward sides, as a rule. This holds true of snow-precipitation as well as rain, though the snowfall is less prompt and less well localized. Where mountain ranges are broad and complex the snow caught on the windward side is usually greater than that which lodges on the leeward side, and the glaciers on the windward sides of mountain ranges are usually larger than those on the leeward sides. But such *general* community of distribution does not hold in detail, for the wind comes in as a

local differentiating agency. Acting on rain, wind increases the amount per unit area that strikes the surface of an eminence on its windward side; it also somewhat increases the force of the impact on that side. On the other hand, wind tends to drive falling and fallen snow around the wind-swept side of the eminence into its lee and to heap it up in the eddies there, and on the areas protected from the wind. Thus the snowfall that, in the absence

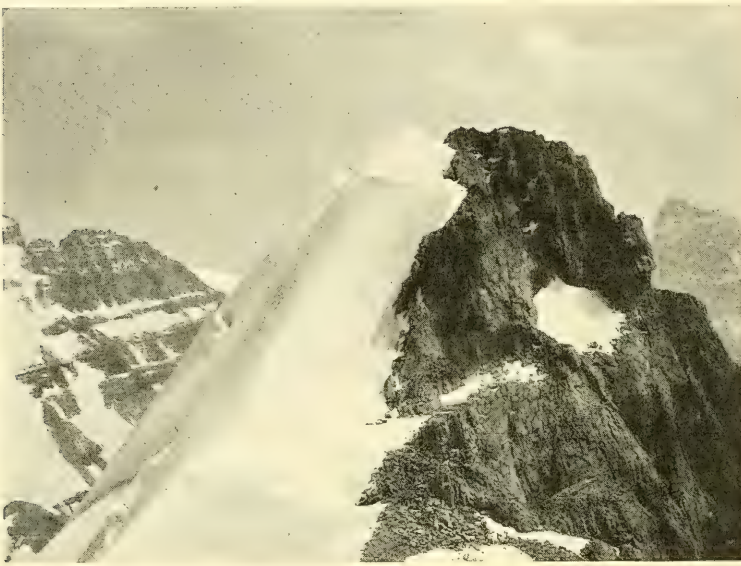

FIG. 1.—Snow lodgment on the side of the summit ridge of Mt. Victoria, Canadian Rockies. This ridge forms the continental divide. The snow has lodged on the Eastern or Albertan side in the lee of the crest. Photo. by R. T. C.

of wind, would come to rest on the windward and lateral slopes of an eminence and later must drain away on these slopes is, under the action of wind, concentrated notably in patches in the lee. Considered therefore in detail, rain action is somewhat intensified on the windward side of prominences, while snow lodgment, leading on toward glacial action, is more markedly concentrated on their leeward slopes.

The field use of this distinctive localization of rain-work and of snow-work respectively is qualified by the fact that, while the

prevalent air movement of a region may be nearly constant in *general*, the cyclonic movements that are the immediate agents that bring on precipitation introduce variation in the *particular* direction from which the wind blows at the critical time when the storm is on and the distinctive work in question is done. In the mid-latitudes of the northern hemispheres, the general air movement is toward the east but at the times of storms the wind not uncommonly comes from the eastward. However, the general law that snow lodgment is most abundant on the prevailingly leeward sides of prominences seems to hold good. This is greatly aided by the shifting that takes place in the intervals between storms.

The fact that the eddies formed in the lee of crests, domes, and knobs are the common spots of lodgment carries as a corollary the observation that the forms of the snowfields are usually broad, or ovoid. The windward edge is usually arched, and is often thickened near its upper border. Not unfrequently the thickened snow mass is wider transversely than in the line of slope. Often, too, it must be noted, the lodgment is concentrated in ravines and valleys that were shaped previously by drainage erosion, and in such cases the localization is less distinctive.

The case best suited to a discriminative study is a broad or transversely elongate lodgment of snow in the lee of a well-rounded eminence from which the normal run-off is divergent. So long as such a snow mass lies passively where it lodged, there can be little doubt that it is protective rather than erosive, when compared with normal surface action. So long, too, as the later action is confined to a slow annual melting of the snow and a quiet run-off of the resulting water, the snow and water combined perhaps do less erosive work, on the whole, than would be done by the more forceful impact and the more prompt run-off of the equivalent rain, though qualifying conditions must be recognized on both sides.

The case of snow vs. rain, under these conditions, is not more than debatable at most and the modes of erosion in the two cases are essentially identical.

But when the snow accumulates perennially so as to move as snow-ice in glacier fashion, the modes of erosion become diverse,

and *the configuration of the eroded surface* is the test of the dominance of the one or the other type. It is obvious that the least eroded part of the eminence must come to stand forth and the

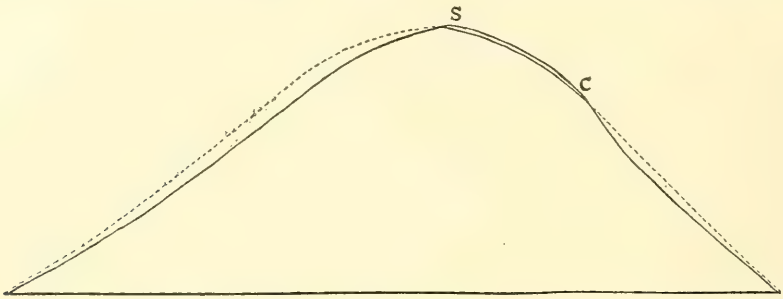

FIG. 2.—Diagram to illustrate the effect of erosion upon a hill, on the assumption that the capping of ice, SC, is protective. The dotted line represents the original outline of the hill; the solid line, the contour resulting from erosion.

most eroded part must retire toward the center. If the snow-covered flank or brow is indeed a protected area, it must gradually come to stand forth from the retiring wear-and-weather contours

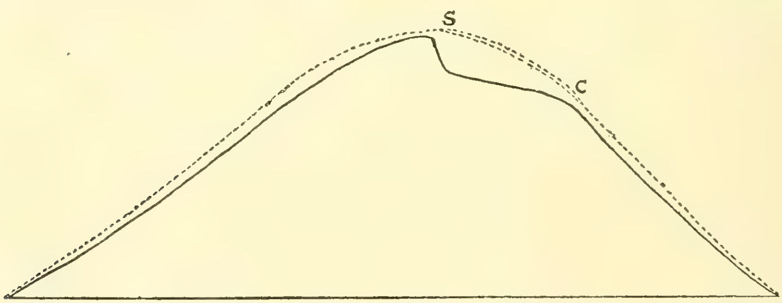

FIG. 3.—The same hill as in Fig. 2, eroded according to the hypothesis that ice is a superior eroding agent. SC represents the original snow bank which comes to occupy a basin as erosion goes on.

adjacent, as a rather definite embossment, as illustrated in Fig. 2. As time goes on, the summit of the hill should migrate toward this protected area and it should tend to become the summit, while the snow-cap in turn migrates into its lee. A marked asymmetry should gradually develop.

On the other hand, if the snow mass, accumulating from year

to year, comes to take on motion as a glacial body, the erosion to which its motion gives rise must take a form coincident with the moving part of the snow-ice mass. The erosion is assumed to be due to the adhesion of the snow-ice mass to the ground on which it rests—to the soil and loose rock at the start, to the progressively loosened and ground rock below later. A broad patch of soil and loose rock coincident in form with the moving part of the snow mass is first dragged away and the configuration of the scar is distinctive of the action. If erosion beneath the moving glacier mass continues the excavation will in time come to have the form shown in Fig. 3. Such excavations are to be looked upon as embryo cirques. They are found on the lee crests, brows, and slopes of round-topped mountains known to have been subjected to local glaciation. Less typical initial cirques are formed in ravines where snow lodgment gives rise to glaciers.

If absolute certainty that there has never been any previous glacial action in a given region is regarded as a prerequisite to an irreproachable illustration of this class of actions, such a case is difficult to demonstrate because the configurations left by the older glaciations have often been so largely lost in the subsequent sculpturing of the common wear-and-weather type that the absence of previous glacial work is hard to prove in regions likely to have been glaciated recently, but this is only a question between the work of different glacial stages, not between glacial and aqueous methods. But though a region has been subjected to previous *general* glaciation, even rather recently, geologically speaking, the typical effects of local glaciation on rounded contours are discernible much as in wholly unglaciated regions, for the contours shaped by the *general* ice movement conform to the dominant horizontality or the low inclination of such general ice movements, while the lines of local ice movement are decisively downward in conformity to the *local* slope.

These considerations are here put in the theoretical form, but they suggested themselves almost as inductions during a summer trip along the coast of Norway in 1909. They arose naturally from the abundant and instructive phenomena of that region, where former glacial action merges into present action. The configurations

wrought by the older general glaciations do not seriously mask the distinctive work of the local glaciation that has followed and is, in some part, in action still. Broad excavations of the initial cirque type are common on the brows and slopes of the rounded mountains and on the islands that fringe this coast and on the mainland itself. They seemed to us clearly to be more common on the eastward sides of the islands than on the westward. The initial types are chiefly the products of modern action; indeed in

FIG. 4.—Basins hollowed in a hillside by tiny glaciers. From the coast of Norway. Photo. by R. T. C.

many cases the basins are still occupied by the snow-ice mass to which their shaping is due. The whole series taken together show various stages of the work of snow accumulation and earth excavation. Small, relatively wide basins, scooped broadly from hillsides, are variously occupied or empty according to altitude, latitude, or other condition favoring snow accretion or snow wastage. Their dimensions range downward to hollows not unlike pits on the brows of drift hills and upward to mountain cirques of typical form and magnitude. They also range from mere cirque heads to cirque heads with short glacial appendages and thence on to longer and longer glacial tails until the peculiarities of the

head-work in the cirques are lost in the more familiar body-work and tail-work of the more accessible parts. Various stages and transitions are shown in the accompanying photographs.

Fig. 4 shows five well-developed basins escalloped in a hillside. The two hollows on the left are round and wide and terminate below in well-defined platforms or steps at nearly the same level.

FIG. 5.—A concave scallop on the brow of a projecting embossment. Apparently this is the work of sapping by the ice at the base of the cliff. Note the rounded convex glacier-polished outlines of the rest of the embossment. In the background is the Lyskamm, central Pennine Alps. Photo. by R. T. C.

They are approximately as wide as they are long, showing that the ice which accumulated there has eaten its way in a distinctly broad fashion into the rock slope on which it lay. The vertical distance which any given part of the ice has moved its rock is small relative to the total amount of transportation accomplished. The work has been done very locally compared with the longitudinal movement of typical water action. The next two basins continue down the slopes to points much nearer to the sea. There has been

more advance movement of the ice here. The basin on the right has become a glacial valley in an embryonic stage and the work of water erosion seems to form a larger factor.

Sculpturing of similar sort is illustrated by Fig. 5, from the Swiss Alps. The brow of a long spur descending from the Zwillinge has been scooped and hollowed in concave fashion by the sapping action of glacier ice. Occurring in the midst of a still

Fig. 6.—The Glacier des Grandes Jorasses on the Italian side of the chain of Mont Blanc. The ice has sunk its bed into the rocky mountain wall and worked backward as implied by the distinct bench upon which it rests. Photo. by R. T. C.

strongly glaciated area, this case is interesting for the reason that such sculpturing has been at work here for a comparatively short time only. The rounded rock contours below and to the right of the hollow excavation have at no distant date been scraped and polished by the larger glaciers descending from the peaks above. The ordinary abrasive action of a moving body of ice is here illustrated. But the much smaller mass of snow and ice at the base of the cliff in the hollow appears to have operated in the very different and more potent manner of basal sapping at the schrund line.

Fig. 6, from the chain of Mont Blanc, represents the Glacier des Grandes Jorasses on the Italian side of the rugged mountain mass of the same name. Other similar glaciers to the left and right have etched their basins into the upper slopes of this great mountain rampart. These glacier-filled basins are deeply sunken and are as broad or broader near the base of their cirque walls than they are farther down toward the ends of the present ice tongues. At their heads they are terminated by precipitous rock walls. Extremely precipitous cliffs come down to the Glacier de Rochfort from the Aiguille du Géant and the col between it and the Aiguilles Marbrées. From these rock walls behind the ice there is a very decided change in slope to the gentle incline of the glacier floor below. In just the same way there is a very abrupt change of slope from the precipitous rocks of the Grandes Jorasses and Mont Mallet to the very moderately inclined surface of the Glacier des Grandes Jorasses at the foot of these steep cliffs. It is at the point where these cliffs join the less inclined basin floor beneath the glacier that the greatest cutting has occurred. Such a profile of cliff and floor coming together at a sharp angle is quite unlike any gully erosion developed by ordinary running water in mountains of massive crystalline rocks. The greatest cutting has been beneath the glacier in the neighborhood of the bergschrund and directed backward into the mountain.

II. CERTAIN SIGNIFICANT POSITIONS OF CIRQUES

In our sketch of the initiation of cirques, we gave preference to cases located on leeward aspects of eminences favorable for snow lodgment but unfavorable for the concentration of running water. We noted that if the lee brow were *protected* by its snow covering, the crest should slowly shift toward the protected spot and the protecting snow-cap should shift in turn to its lee and thus combine to shape forth an asymmetrical mountain horn. On the other hand, if the snow mass becomes a superior *erosive* agent when it begins motion, and digs out a broad basin which in turn adds to the catchment of snow, and if at the same time the embryonic glacier stopes headward, it, in its way, *moves toward a summit position.* It is clear that rainfall does not concentrate toward

the summit of a rounded eminence in this way. Its trenches do advance headward, but they take the form of ravines, gulches, and gullies eating sharply, not broadly, backward. The positions of cirques that are fully developed may be studied for evidence confirmatory of these deductions. In such study perhaps the most striking illustration of summit-ward creep is found in the *crater cirques,* a form that has attracted the attention of observant travelers but has not played as large a part in glacial literature as

Fig. 7.—The Rendalstind on the west side of the Lyngenfjord, Norway. The summit has become crater-shaped by ice sculpturing. Photo. by R. T. C.

perhaps it should. Mountains with crater-like summits are quite common along the Norwegian coast above the Arctic Circle, and they are likewise frequent enough in the Lofoten Islands to give characteristic profiles to the views obtained there from passing steamers.

The Rendalstind, on the west side of the Lyngenfjord (Fig. 7), is an illustration of the type in a not very advanced stage of development. Glacier action in the summit basin is today actively in progress. Other mountains of the region reveal much more pronounced sculpturing of this sort where the action has either been more prolonged or more intense. Such a case is illustrated by

Fig. 8. This crater mountain, which happens to be crossed by the 70th parallel, comprises the north end of Kaagö Island. Originally it appears clearly to have been a more or less rounded dome or knob. A cirque starting with snow lodgment high up on the northeast slope of this eminence appears to have worked back

Fig. 8.—A crater-like mountain top in a more advanced stage of erosion. The outer slopes of the conical mass show the familiar abrasive action of past general glaciation together with the lines of ordinary meteoric erosion. The steep walls of crater-like cirque are due to sapping by localized glaciers of late date. Kaagö Island, coast of Norway. Photo. by R. T. C.

toward the summit by a stoping process until the cirque pit has come to occupy a sub-summit position. The mountain top has been hollowed out and now only a shell remains in place of the former flat-topped mass. It is like a volcanic crater broken down on one side. The inner walls are steep and cirque-like and the crater portion is filled with deep snow. Water erosion is not adapted to this sort of sculpturing. The central basin with circular cirque cliffs gives every appearance of having resulted from

Fig. 9.—A very capacious summit cirque in the San Juan Mountains of Colorado. Seen looking southeast from the culminating point of St. Sophia Ridge, Telluride quadrangle. The points of note are the breadth of the cirque basin and the narrowness of the serrate rim. The abrupt step in the middle of the basin while partly the result of stoping beneath the body of the glacier was also probably in part determined by differences in the resistance of the rock formation. Photo. by R. T. C.

continued sapping and quarrying by glaciers eating their way backward much as they have in the Alpine cases cited.

Fig. 9, from the San Juan Mountains of southwestern Colorado, is a striking example of a much more capacious summit cirque. The basin here is very broad, with a nearly level floor, while the cirque rim has been undercut till only a narrow horseshoe-shaped serrate ridge remains. Its jagged crest varies in altitude from 13,000 to 13,200 feet, while the mean elevation of the broad floor is about 12,800 feet. The breadth of the basin and the steepness and thinness of the amphitheater walls that skirt it show that this type of action has here gone about as far as it well could as a single stoping operation. The whole constitutes a signal case at its very climax.

In the light of these illustrations, particularly Figs. 8 and 9, there seems no ground to doubt that the erosion suffered by the non-glaciated parts in such situations at least falls greatly behind that suffered by the parts covered by ice.

III. THE DISTINCTIVE WORKING FACTOR

The decided superiority of moving ice over moving water as an erosive agent lies chiefly, we think, in the rigid hold of the ice on matter set in its base or sides. This is sharply contrasted with the adhesion of water which is so feeble as to scarcely warrant the term "hold" at all. Water action finds some compensation, indeed, in the higher velocity it usually gives to the matter it carries, but near the point of origin of action—and this is the location chiefly under discussion here—the water is so distributed as not to be able to acquire much efficiency from concentration. The ice mass, on the contrary, is rigidly unified; its velocity is indeed low, but its mass and fixed coherence are high. It is in respect to this coherence that exaggerated views of the viscousness of ice are perhaps most misleading. Rigidity of grasp and mechanical firmness of action are specifically implied in the groovings, gougings, and crushings that distinguish the action of glaciers. Effectiveness of corrasive action is further implied in the chemical and physical nature of the rock-flour and fragments which these groovings, grindings, and crushings contribute to the glacial till

and to the wash-products immediately derived from it through glacio-fluvial assortment.[1] The graving of a glacier's bed by rock fragments set in its base or sides may be cited as specific evidence of an essentially rigid hold on the graving tools, and of an internally rigid, rather than fluent, motion of the mass holding the tools. The glacial grindings that are borne out with the subglacial waters and give milkiness to glacial streams seem to us irrefutable evidence of effective rasping and grooving of the rigid type, not of simple viscous overcreep. The very marked contrast between the turbid waters that flow from beneath glaciers and the relatively clear waters that flow down adjacent unglaciated valleys is very impressive and spectacular evidence of the superior erosive powers of glaciers.

Closely allied to this lesson from grindings in transit is a less obtrusive one drawn from the contrast in the points where coarser matter which only strong transporting agents can handle is concentrated respectively in glaciated and in non-glaciated valleys in regions of the same general type. The upper parts of non-glaciated mountain valleys in cold regions are usually burdened with heavy talus and large loose masses which the drainage is unable to carry away, while the glaciated parts of similar valleys are usually well scoured out and the moutonnéed sides and bottoms of U-shaped troughs take the place of the craggy outliers of V-shaped trenches in unglaciated valleys. But in the lower portions of the glaciated valleys below the reach of recent glacial action, *aggradation* very generally prevails, while in similar non-glaciated valleys *degradation* generally prevails, if not absolutely, at least relatively. Students of Alpine regions will recall multitudes of illustrations. A similar lesson is even more impressively enforced on the borders of the late Pleistocene glacial areas. In strong contrast to the state of the valleys of the adjacent driftless regions, the great glacio-fluvial valley trains with their thick heads next to the ice border, as well as the frontal aprons, show very conclusively the overladen condition of the glacial waters and their marked incompetency to fully carry away their burdens.

[1] "Hillocks of Angular Gravel and Disturbed Stratification," *Am. Jour. Sci.*, XXVII (May, 1884), 378–90.

Now the regional precipitation is much the same for like areas and like situations in the glaciated and in the non-glaciated valleys. Such differences as there may be appear to favor a greater run-off in the glaciated than in the non-glaciated basins, for the former are likely to be cooler and hence better condensers and the concentration of snow by wind action is there more effective. If so, the advantage in absolute carrying power lies with the waters of the glaciated valleys. If therefore the passing of a part of the precipitation through the glacial form and the moving of this part, so far as it moves as ice, is *protective,* the débris should tend to remain in the upper glaciated sections thus protected; while the waters of the valley below the glacier having some excess in volume and having less burden to carry should tend to degrade the lower reaches of the valley more effectively than if the glacier were absent. That the facts are precisely the opposite seems good additional evidence that the glacial form of water compared with the aqueous form increases notably the corrasion and the transporting power. And so it seems to us that the fringing outwash aprons and the thick-headed valley trains of the Pleistocene join with the aggraded states of the lower stretches of present glacial valleys and with their turbid glacial streams, their moutonnéed walls, and their glacial scorings to testify to the superior erosive efficiency of glaciers.

Traced back analytically to the properties that gave rise to them, these corrasive products point to a glacier's power to take firm hold on rock fragments imbedded in its base and sides and move them on while it uses them as graving tools. A special feature that is of interest here is the ice's habit of freezing to fragments in contact with it, especially when moisture is present. Ice also strengthens its adhesions by a tendency to freeze and thus to attach additional ice at points where tension is developed. This amounts to an inherent tendency to strengthen its hold when threatened with severance.

IV. THE EVOLUTION OF THE CIRQUE

In a young glacier-head just coming into action as the result of the growth of its stresses as a snow mass, it is inevitable that

at some point near the upper edge of the snow mass there should come to be a line of strain between the thicker part below that is forced to move and the thinner part above that lacks sufficient stress to take on motion. A low temperature is essential to the preservation of the elements that enter into the process. Through this low temperature the snow-ice mass has become adherent to the soil beneath it and more or less interlocked with the loose rock that may be at or near the surface. The motion of the snow-ice mass involves the motion of some part of this underlying material. Under the snow-protected stationary part the loose earth-surface remains behind. The line of division between the stationary protective snow and the moving abrasive snow-ice mass thus demarks a scar and this scar, if we interpret aright, is the embryo of the future cirque. As the process goes on and the excavation becomes deeper and by this deepening comes itself to aid in the catchment process, the line of transition from the ineffectively thin snow above to the effective deep snow below becomes more sharply defined. Thus the delimitation of the growing glacier-head and its product, the growing cirque, not only becomes more pronounced but the line of parting between the active and the inert becomes fixed by the process itself; and so the declared cirque becomes established and its bergschrund localized. With further progress the action graduates into the still more declared forms of the cirque-generating process.

In the exposition of Willard D. Johnson[1] as also in that of G. K. Gilbert,[2] both of which we accept in the main, the bergschrund is made the dominant agency in the cirque formation. The view just outlined carries the cirque-forming action back of even the cirque itself and, potentially at least, back of any bergschrund or any possible influence arising from the bergschrund. It makes the bergschrund and the cirque-development sequent on conditions and agencies that at an earlier stage controlled the snow-ice accumu-

[1] Willard D. Johnson, "The Profile of Maturity in Alpine Glacial Erosion," *Jour. of Geol.*, XII (1904), 569–78. Earlier papers are "An Unrecognized Process in Glacial Erosion," *Science* (1899), p. 106; "The Work of Glaciers in High Mountains," *ibid.*, 112–13.

[2] G. K. Gilbert, "Systematic Asymmetry of Crest Lines in the High Sierra of California," *Jour. of Geol.*, XII, 579–88.

lation and brought on motion in the thicker part of the mass while it left the thinner part stationary and protective. The bergschrund and the cirque cliff are themselves made sequences of a mobility and erosive competency more primitive than themselves. This in turn is contrasted with adjacent inertness and erosive inefficiency.

All this, however, seems to us wholly compatible with a cordial acceptance of the bergschrund and the cirque wall as auxiliary sequential agencies which strikingly abet the more primitive actions that brought them into being. Much as the bergschrund may aid the backward sapping of the cirque wall, we think that the more fundamental agencies are to be regarded as controlling the process throughout its history.

As already implied, a marked peculiarity of ice, shared in equal degree by no other familiar body, is its tendency to grow under tension and to form adhesions by such growth at the points where tension has been developed. When forced to part, ice parts suddenly by abrupt fracture attended by the elastic recoil of the separated faces. In this its action is in marked contrast to the separation of viscid bodies, which part by a gradual weakening and stretching under continued strain. Within the bergschrund, as also elsewhere and in general, the predisposition of the ice, when at the critical temperature of congelation and below, is to freeze to whatever falls in from the surface or is loosened from the walls. This tendency to form adhesions is no doubt especially active at the base of the schrund and at the foot of the cirque wall, where the convergence of the walls wedges all such matter together and where the conditions of temperature and moisture are likely to be favorable to glacial attachments in the active season. Whatever snow falls in, slides in, or is blown into the gaping mouth of the schrund, and whatever rock is detached from the cirque wall by the freezing of such waters as may come down the bergschrund are subject to such attachment to the head of the glacier and to removal by it as it moves, as Johnson has indicated. In addition to this, such waters as enter the mountain at any point above the cirque and traverse internal joints and later come out to the face of the cirque wall lower down are subject to freezing as they come near the

exposed portions of the face, and by expansion in the joints are likely to rive the wall rock and to detach fragments from it. It seems probable from the nature of the case that the exit of such internal drainage takes place more largely at or near the foot of the cirque wall than at higher levels. Such a localization of the action is specially fitted to promote basal sapping. If the sapping at the base of the cirque wall be thus made in some notable part dependent on the seepage of water from the mountain mass at or near the base of the wall, it will not perhaps seem strange that the sapping should proceed somewhat downward as well as backward, following in reverse the direction that the waters of seeps and springs usually take in issuing, and thus give rise to the important fact observed by Johnson that the floor of the cirque frequently inclines somewhat toward the cirque wall.[1]

In this view, the sapping is not made in any radical way dependent on diurnal changes of temperature due to the openness of the schrund above; rather it presumes that the base of the schrund will often be filled with snow, ice, or rock fragments fallen from above and that it will not be freely exposed to the briefer class of changes of temperature that affect the outer air. It does presume, however, that the mean temperature at the base of the schrund, and at the base of this part of the glacier generally, favors freezing whenever tension aids, and that it is favorable to glacial growth rather than glacial wastage, as this is the general fact in this part of a glacier. The periodicities of seasonal temperature and the variations attending the cyclonic movements of the atmosphere extending over some days seem to us more probably effective in the sapping at the base of the cirque wall than daily changes.

V. GLACIAL STEPS

Conditions somewhat similar to those of the cirque, save in the matter of the beginnings of motion, are often found at other points along the length of the glacier below the cirque. They do not seem to be in any way dependent on the existence or the absence of a declared cirque at the head of the glacier. If a glacier takes origin in a sharp gulch or in a pointed valley, a typical cirque

[1] Willard D. Johnson, *Jour. of Geol.*, XII, 576.

may not develop, but this does not affect the behavior of the glacier below. If a pre-existent step or down-set crosses the bottom of the valley at any point beneath a glacier, or if a step is developed by structural inequalities, and if the down-set is sufficiently great in proportion to the thickness of the ice to cause effective crevassing

Fig. 10.—View from the Bäregg in the Bernese Oberland, Switzerland. At the bottom of the picture below the ice fall is the comparatively level Lower Eismeer of the Unter Grindelwald Glacier. Above the ice cascade is another higher ice plateau known as the Fiescherfirn, limited by the slope seen in the perspective. Peeping through the mists high above is the point of the Grosse Fiescherhorn. Photo. by R. T. C.

through the whole depth of the glacier, the conditions at the base of the step are not radically different from those at the base of the cirque wall, for there is in effect a break in the continuity of the motion of the glacier and the beginning of a new motion in the ice mass below. The rock face of the step may be regarded as a cirque wall in a modified sense. From it masses may be detached and, falling against the ice wall, become attached and dragged

forward. At the brink of the step-wall special weighting is likely to be brought to bear by the pushing of the ice forward over the brink before it breaks and drops down, and this probably leads to some splitting off of the edge of the wall. This action naturally tends to give slope to the step and to modify it in the direction of a cataract as distinguished from a cirque, but the essence of the phenomenon is probably much the same in either case. Sapping and stoping seem to be rather general phenomena of the basal action of glaciers.

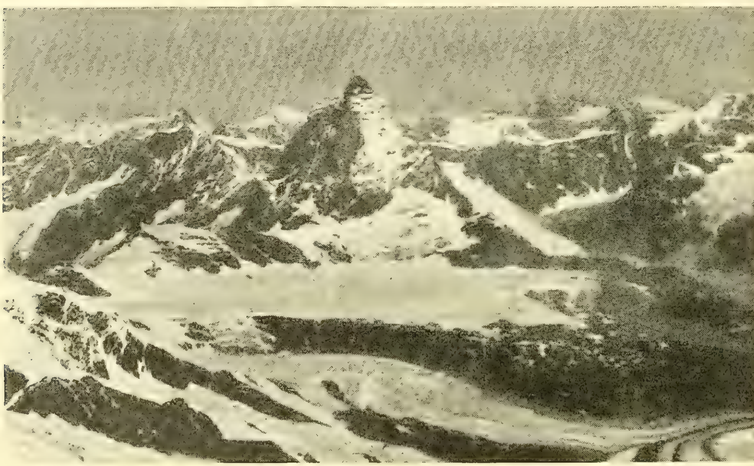

FIG. 11.—The Furgg Glacier, a broad, flat, ice sheet at the east base of the Matterhorn. Both above and below this nearly level glacier-made shelf are steep cliffs. Photo. by R. T. C.

The operation of the stoping process at several points in a long glacier tongue, by developing successive ice falls between more or less level stretches, results in a rude stairway of giant tread. A portion of such a glacial stairway is shown in Fig. 10. This is the Unter Grindelwald Glacier viewed from the Bäregg. Two comparatively level stretches of glacier are visible—one above the prominent ice cascade, the other below it. They are known respectively as the Fiescherfirn and the Lower Eismeer. Dropping from the Grosse Fiescherhorn and lofty Fieschergrat to the gently

sloping Fiescherfirn are steep ice-clad slopes—the upper cirque walls. Dropping in turn from the Fiescherfirn to the Lower Eismeer is the ice cascade in the center of the picture. To the right beyond the range of this picture the level Eismeer plunges over another ice fall toward the Lütchine valley below. The last plunge, however, is perhaps more in the nature of a hanging valley at the approach to the main valley. Cataracts due to the fall of

FIG. 12.—Nearer view of the head of the level Furgg ice sheet and the Furggen Grat, whose precipitous walls are being undermined. View from the Matterhorn hut. Photo. by R. T. C.

glaciers from hanging valleys into main valleys are frequent but necessarily occur at or near the junction of the valleys. Cataracts occurring at intervals along the course of a single ice stream are presumed to be correlated with stoping action.

Fig. 11 is introduced as an example of a flat plateau-like glacier-covered tract intermediate between the mountain heights behind it and the lower valley in front. This flat plateau covers an area of approximately four square miles at a mean altitude of about 10,000 feet above the sea. Ice cascades descend toward the

lower valley from either end of it. Behind are the abrupt cliffs of the Matterhorn and the Furggen Grat (Fig. 12). The very sharp angle between the steep wall of the Furggen Grat and the Furgg Glacier which is pulling away from it affords strong evidence of the effectiveness of sapping at this critical location.

VI. BASAL SIDE EROSION

The sapping and corrasion along the side-base of a glacial valley, by which the normal V-shape is converted into the glacial U-shape, is perhaps due mainly to the better supply of carving tools furnished the sides of the glacier by infall and inwash from the slopes and cliffs on the valley sides, and by seepage from the side walls. This supposes a general similarity between the conditions at the side of the valley and those at the cirque base, except that the direction of glacial motion is different.

All these distinctive phenomena of glaciers seem to us to be expressions at once of the peculiarities of glacial erosion and of its superiority where conditions favor glacial erosion.

This view does not, however, make the superiority universal and unqualified. Obviously it does not exclude the view that snow fields while they remain in the passive state serve as protective agencies. Nor does it exclude the view that the center of a continental ice field, from which the motion is mainly radiant and limited in amount, may be protective rather than erosive when compared with normal weathering. Nor does it exclude the view that valley glaciers in some of their parts may be less erosive than normal wear and weathering would be. But these seem to us rather qualifications of the general proposition that glaciers are effective agents of erosion than contraventions of it.

VALLEY FILLING BY INTERMITTENT STREAMS

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Streams having steep grades are usually thought to be in active vertical erosion. The writer finds, however, that many intermittent streams are not degrading but are actively aggrading parts or all of their valleys. One of the best examples of such valley filling is that of Jewell's Creek, described in this article.

This little valley is found on the right bank of the Huron River about two miles above the city of Ypsilanti. The Ann Arbor sheet (U.S.G.S.) shows it as a mere ravine to the west of the little settlement of Superior. The accompanying map shows that the valley is about eight hundred and fifty feet long and that the headwaters are eighty-five feet above the Huron River. The line marking the west boundary of the map is on the line of a fence. The land to the west is under cultivation. The main stream has two tributaries, one from the southwest which enters near the mouth, and another from the northwest, joining the main stream near the head waters. Both of these branches head into cultivated fields.

The main valley is divided into two distinct parts. Above where the forty-five-foot contour line crosses the valley, the flow of the water is intermittent. The floor is thereby mostly dry and covered with a species of grass that can live under dry conditions for part of the year. Below the forty-five-foot contour line the flow of water is constant throughout the year. Here the bottom is mostly wet and covered with swamp grass, which greatly retards the flow of water. Fig. 2, taken from a point near the mouth, gives a good idea of the lower part of the valley; while Fig. 3 gives a view of the middle portion just above the crossing of the forty-five-foot contour. The stump shown in the face of the small cliff in the foreground is indicated on the map by the letter *S*, the trees are indicated by circles, and the cattle are standing just about where the fifty-foot contour line crosses the flat bottom of the

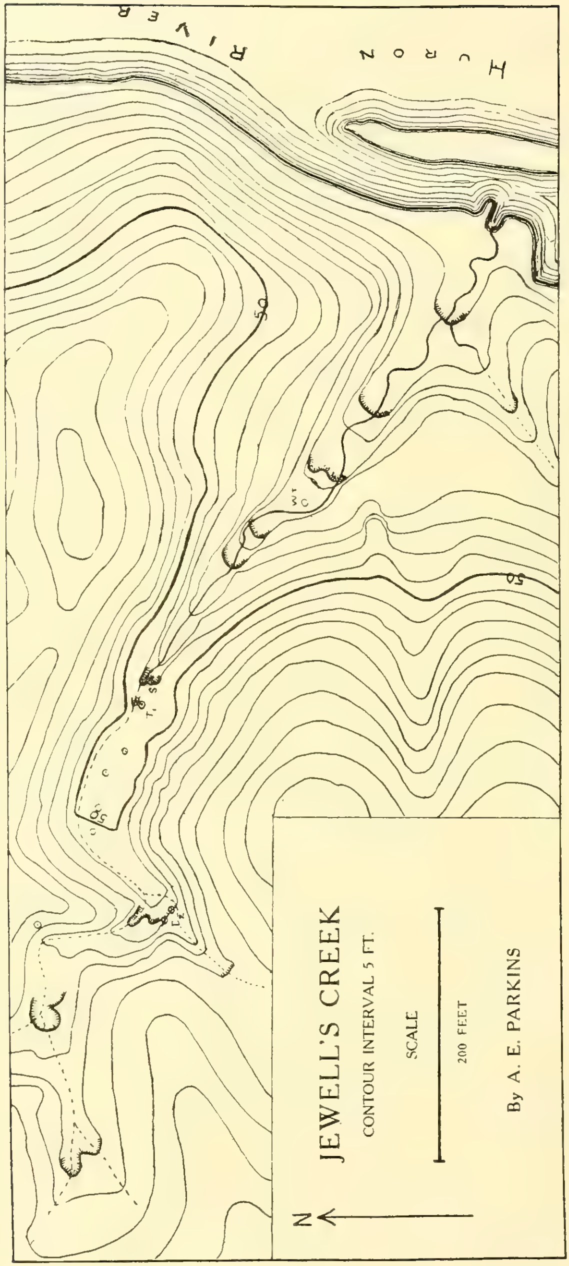
HURON RIVER
50
50
50
JEWELL'S CREEK
CONTOUR INTERVAL 5 FT.
SCALE
200 FEET
By A. E. PARKINS
N

Fig. 1

valley. From both the pictures and the map we see that throughout the whole valley we have steps and above each step the valley bottom is flat floored. Only at one point in the valley, just below the forty-five-foot point, is it V-shaped.

The flat floor indicates filling. This is best seen perhaps in Fig. 3. This view also gives other convincing evidences. The sharp angle between the valley sides and bottom is a good evidence, the buried "feet" of the trees is another, and the most convincing of all is the position of the stump in the face of the bank or cliff. Just above the roots, where the surface of the ground is found with most trees, is a dark layer of soil about three inches thick. This marks the level of the valley bottom before filling. The view also shows that active erosion is going on at this point causing the step to recede up stream. This recession takes place only during and after rain storms and wet weather in the spring. The material taken from here goes to build up the steps in the lower part of the valley.

FIG. 2.—The lower part of the valley. In this part there is a continuous flow of water throughout the year, it being below the water table. The water course is much choked with grass. One step may be seen just this side of the tree, a walnut, in the valley bottom near the middle of the picture. On the map the location of the tree is designated by *W. T.*

But where does the material come from that is filling the valley above this step and all the way to the headwaters? All over the valley floor above this point we find fresh sand and gravel. Since there is no evidence that it comes from the sides, it must come from the collecting basins drained by the headwaters of this stream.

FIG. 3.—A view of the middle part of the valley. The forty-five-foot contour crosses on the edge of the tiny cliff. This view shows the flatness of the floor, the sharp angle between the valley sides and bottom, the buried "feet" of the tree and the stump.

The fact that the headwaters lead from cultivated lands leads one to suspect that here is the source of the material, and that the valley began to be aggraded when the forests were cut off and the soil loosened by the plow. This being so, filling must have taken place since the arrival of man in this section. Just how long ago that was, is not easy to determine from anything in the valley, except what evidence may be presented by the stump.

Evidently that seventy-five- or eighty-year-old tree started as a sapling in the valley bottom when the surface was two and one-half feet below the present surface and on a level with the upper portion of dark soil. Filling must have taken place some time within the seventy-five or eighty years. It is probable that filling has extended over many years and was and is necessarily intermittent during the year and intermittent during periods of years, less waste being furnished when the field to the west is in sod and during the dry periods of the year.

If all these suppositions be true, one would be led to make the statement that *all valleys of intermittent streams that head in cultivated fields are waste filled.* To test this generalization search was accordingly made and within a quarter of a mile from Jewell's Creek three others were found that showed essentially the same features as here described. Later, other valleys were examined, in all about a dozen, and invariably it was found that where these streams headed in cultivated fields filling was going on in the valley, the amount of filling depending upon the size of the collecting area and upon the kind of material. Not all showed steps as we have in Jewell's valley, but in most of the valleys this feature was duplicated. It was found that the steps were probably produced by bowlders or brush accumulating in the valley, causing a deposit of leaves and waste on the up-side.

The steps in Jewell's Creek as a rule are higher than any in the other valleys yet examined. The ones that are higher show evidences of their being in rapid though intermittent recession, and from indications on the sides of the valley it is believed that they started farther down the valley where stones and twigs blocked the course of the stream. How could the higher steps be produced then? Let us imagine that we have a gradual slope to the valley floor above this point of blocking, and that at some points the water in times of flood had broken through the grassy cover of the slope and had gouged out a trough with a tiny cliff at the upper portion, as we see just to the north of the walnut tree in both picture and map. Now by recession of this tiny step the cliff at the edge would become higher and higher because the new valley bottom produced by erosion would have less grade than the pre-

vious one. This seems to be the way in which the cliff in Fig. 3 was produced.

From a study of the ten or twelve valleys examined I think it is possible to make the general statements: that valleys of intermittent streams which head in cultivated fields are generally flat floored due to filling; that the filling is intermittent, being affected by kinds of crops, and wet and dry periods; that such valleys are usually characterized by steps; and that these steps are first caused by dams of stones and brush, and may become higher by recession. In all such valleys we have an interruption in the normal cycle of erosion, caused by an increase in the supply of waste brought to the headwaters; and when this supply is decreased the stream will clear away the waste and erosion will go on agreeable to the normal order.

ORIGINAL ICE STRUCTURES PRESERVED IN UNCONSOLIDATED SANDS

CHARLES P. BERKEY AND JESSE E. HYDE

The purpose of this paper is to describe and illustrate certain structures occurring in unconsolidated sands of glacial origin. These structures are so inconsistent with the usual behavior of sands during accumulation that it is believed they point to special conditions that could have prevailed only during the glacial epoch. It may be that they give a clue to marginal structures within the moving ice sheet itself.

The deposit is located in New York City between 134th and 135th streets, west of Broadway. It may be seen from the Riverside viaduct which crosses the Manhattanville depression. It appears as an irregular sand and gravel hill, probably only the remnant of a once much more extensive deposit. While it has been opened at several points to obtain building sand and abnormal features are to be seen in several of them, recent excavation for a building at the corner of 135th Street and Broadway has revealed the most interesting exposures.

With the exception to be noted, assortment of material is excellent. Sands of a wide range in size are extensively represented, usually well assorted and plainly stratified. Rarely the finer silts and clays occur in interstratified streaks. On the other hand, some of the beds are made up of pebbles whose diameters are measured in inches. On the whole the materials are coarse, i.e., sands and gravels rather than silts and clays. The individual layers are usually thin, a few inches only, but some of the finer-grained beds may reach a foot or two in thickness.

The exception to this rather thorough assortment of materials is found in masses of bowlder clay which are intimately associated with the other types. The bowlder-clay structure is very coarse. Bowlders two or three feet through are not unusual and one over six feet in diameter is closely associated with sand and gravel.

FIG. 1.—Assorted sands and gravels standing as steep as 68 degrees at some points. Left is northerly.

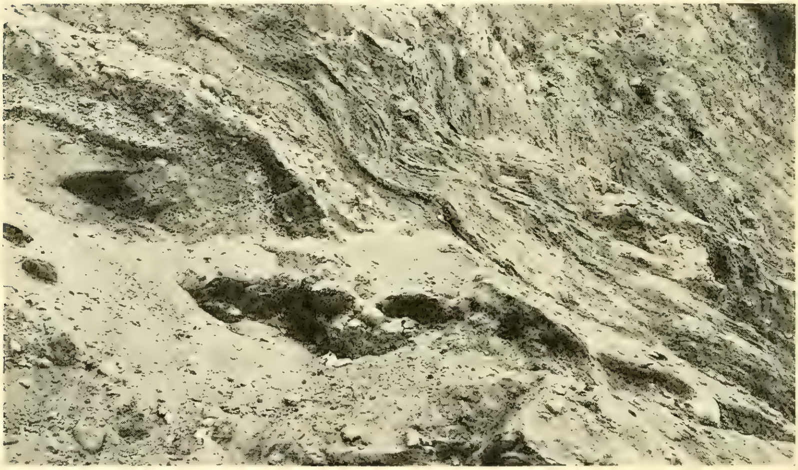

FIG. 2.—Contorted sands associated closely with coarse and unassorted gravels. Right is northerly.

The occurrence of these strikingly unlike deposits so closely interrelated is a prominent feature. Conditions suitable for the handling of large bowlders and the accumulation of till cannot well be regarded as consistent with thorough assorting and deposition of finely stratified sands at the same time and place.

The beds almost never lie flat; when they do it is only for a few inches. They are almost invariably inclined toward the north, northwest, or northeast; that is, against the general ice movement as indicated by striae of the vicinity. Although the maximum angle of repose for unconsolidated sands under subaerial conditions is about 34°, the dips here commonly range from 10° through 20°, 30°, 40°, to 60°. Inclinations of 68° and 71° have been observed and at one point, for a vertical height of four or five feet, the beds are perpendicular or even slightly overturned.[1]

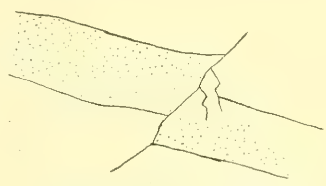

Fig. 3.—Small overthrust in unconsolidated sands, thrust from a general northerly or northwesterly direction.

Occasionally contortion is observed but only to a very limited extent. Faulting of several inches displacement has been seen in such form that it could not possibly have happened by slipping on the growing margin of a delta deposit. In one instance the beds on either side of the fault dip away from the fault plane, on the one side at an angle of 67°, on the other side at an angle of 40°. In another instance a small thrust fault of an inch displacement was observed. It is of significance that the thrust was from the north (Fig. 3).

In order to explain these occurrences and the ones to follow, it may be assumed that the deposit was laid down near the margin of the ice sheet. The material is so well assorted and the bedding is so sharp that it is necessary also to conclude that the deposit was originally water laid. Possibly the dips were originally toward the ice sheet as they are now found, but the angles of inclination could not have been as great as they are now.

[1] Similar structural features are noted by Professor T. C. Chamberlin in gravel hills in Tippecanoe Co., Indiana. ("Hillocks of Angular Gravel and Disturbed Stratification," *A.J.S.*, XXVII [1884], 378–90.)

It seems necessary to assume that, following the deposition, and while the whole mass was thoroughly saturated with water, it was frozen and incorporated in the ice and that there was then

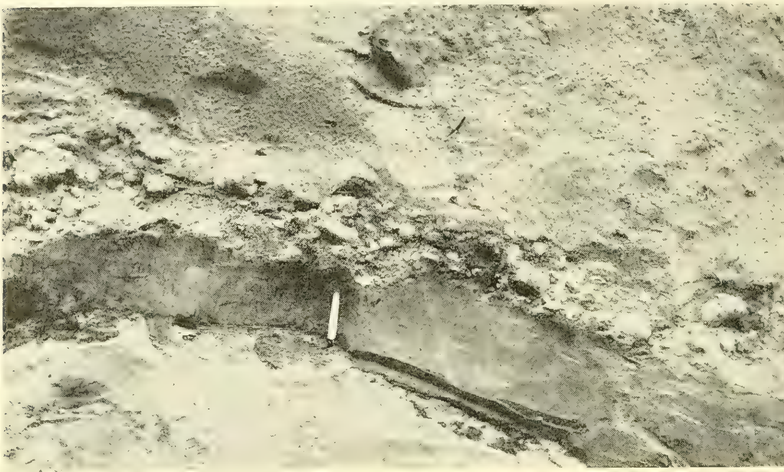

Fig. 4.—A fine sand layer which seems to have been arched since deposition and in the process developed V-shaped notches along the stretched upper margin which are now filled with coarser sand. See explanatory sketch, Fig. 5.

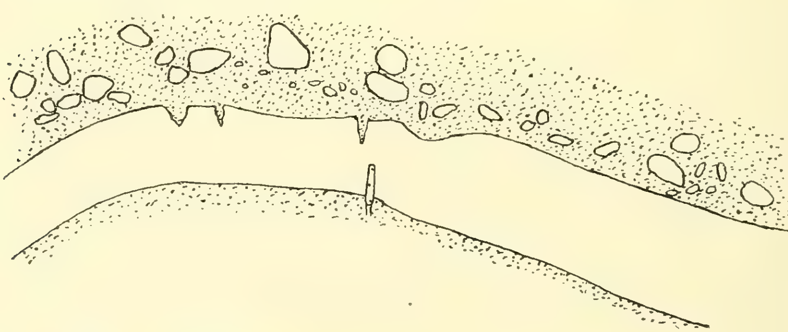

Fig. 5.—Explanatory drawing to accompany the photograph, Fig. 4

movement of the ice sheet with its included material. The movement in the latter, while probably not great, was sufficient to cause the oversteepening of the sands as they are now found, and the slight amount of contortion and faulting which occurs. Under

these conditions probably the interstitial ice became an efficient binder between the individual sand grains and caused the whole to behave as a rock mass, yielding slowly to gradual stresses and breaking or shattering or faulting like a true rock when subjected to sudden changes.

Subsequent melting of the ice left everything in place, and the whole complex mass suffered so little distortion from shrinkage with the loss of its ice matrix that these secondary structural features are still preserved.

With this statement of the thesis some of the minor structures may be described. All of them occur in the finer sand deposits exposed in the excavation at 135th Street and Broadway.

On the south wall there is a low regular arch several feet across in a bed of soft fine clayey sand, perhaps eight inches thick. It is overlain and underlain by much coarser sands. In the upper part there are three narrow vertical cracks some three or four inches deep where the fine sand has been pulled apart, as if by stretching, and the coarse material from above has filled the openings. In this case, the difference in the constitution of the two beds seems to have been a controlling factor and the two types of material behaved somewhat differently, the fine-grained sand layers moving as a unit, and cracking on the upper stretched surface of the arch. The fine sand is now so soft as to be easily pared with a knife and the coarse material runs out from above and below it by its own weight.

At one point on the north wall of the excavation, and less perfectly at several other places, the sand preserves what seems to be the original shattering and cracking of the frozen mass. It is in very fine-grained sand, easily trimmed down without dulling a knife blade. The fracture lines are decidedly darker than the mass of the sand, sufficiently so to bring out the structures in the accompanying photograph. The original sedimentary structure of the sand is preserved and shows distinctly to what extent the whole was crushed and faulted. It is in fact a sand deposit breccia of extremely complicated structure.

A few feet distant from the last, a wholly different structure is preserved. This is in quite fine-grained, clayey sands which

Fig. 6.—Brecciation and minor faulting in unconsolidated stratified sands. For explanatory sketch of the detail see the accompanying drawing, Fig. 7. Left is northwesterly.

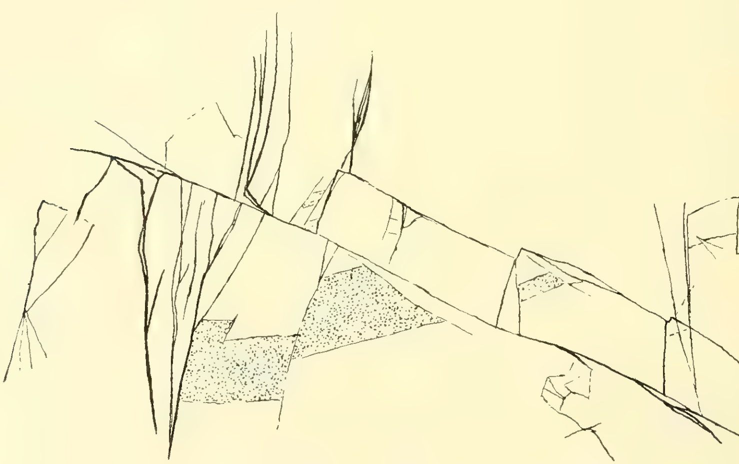

Fig. 7.—Explanatory drawing illustrating the most prominent detail of the photograph, Fig. 6, and compiled in part from other photographs of the same occurrence. Only a few of the angular "fragments" of sand are indicated to show the brecciation.

alternate with several thin streaks of coarse sand, the latter seldom exceeding an inch or two in thickness. These beds are inclined at considerably more than the angle of repose under water, reaching about 40°, and have undoubtedly been oversteepened, although scarcely distorted. Traversing this series is a thin, nearly horizontal bed of rather coarse sand, six feet long and one to three inches thick. This sand is for the most part horizontally bedded, but cross-bedding also occurs, showing that it is undoubtedly water laid in its present position. The remarkable thing is that the cross-streaks of the inclined series are continuous above and below this horizontal streak or layer and are interrupted by it, showing that the horizontal bed came in subsequent to deposition and oversteepening.

It is unquestionable that the beds above and below the horizontal one were once continuous. Assuming them laid down, frozen, and over-steepened as described above, it is postulated that a horizontal crevice was formed in the frozen mass and melting took place along it in the ice and that water currents of sufficient force to carry and rearrange the sands were allowed to enter. With the final thawing of the mass these delicate structures were not destroyed and are still preserved in the unconsolidated sands.

Other occurrences in the same deposit exhibit irregular mixtures of fine and coarse sands in which the finer-grained areas seem to represent a bed that has been broken into distinct blocks or has been drawn out into odd irregular stringers. This gives certain areas, several feet across, the appearance of a coarse breccia in which the finer sand areas constitute the angular masses, while the coarser sands fill up the interstitial spaces like a matrix. Again there are places where the oversteepened layers are so closely associated with others whose attitude is consistent with present conditions that the whole group almost baffles explanation in detail.

In conclusion it may be worth noting that most of the structures described and illustrated could not have been produced in these sands in their present unconsolidated condition. The steeper layers on the other hand could not have been originally deposited in their present attitude. It is necessary to introduce some inter-

mediate history. There is little doubt but that the oversteepening, the brecciation, faulting, and some of the mixing of materials of different types were caused by glacial advance involving the

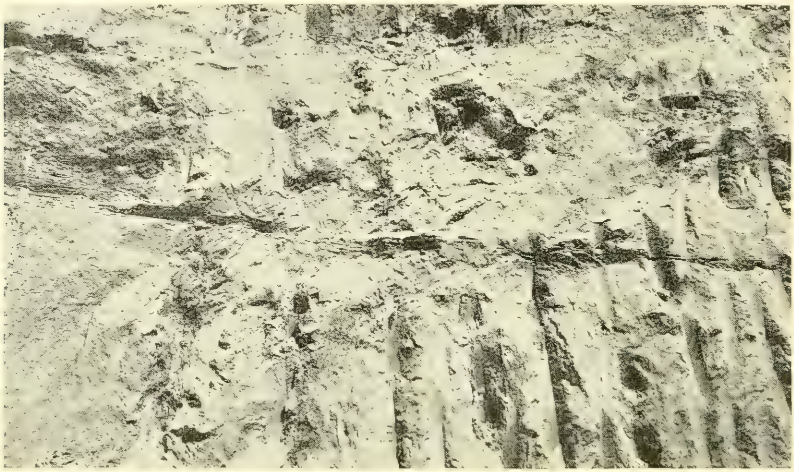

FIG. 8.—Photograph of the thin horizontal sand layer cutting inclined assorted sands. Note the cross-bedding in the horizontal layer at the right. See explanatory drawing, Fig. 9 below. Left is northwesterly.

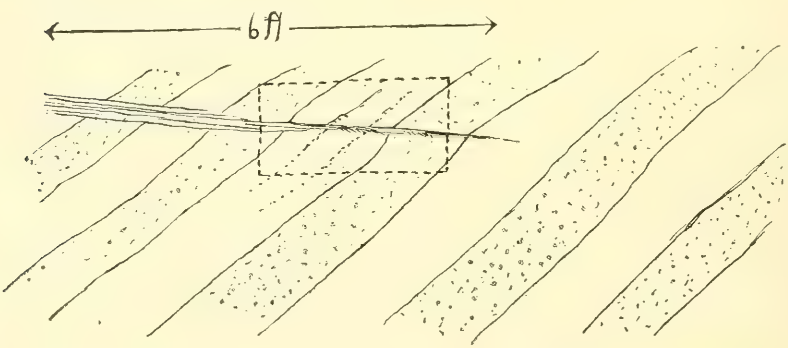

FIG. 9.—Diagrammatic drawing to accompany photograph of inserted sand layer, Fig. 8. The dotted area indicates the portion shown in Fig. 8.

whole mass in some way in differential movements. But before that could be accomplished much of the material had to be assorted, and this had been done, as the great variety and excellent sizing

of grains indicate, under extremely variable conditions and in complex relations to unassorted masses. This seems to point to marginal and superglacial accumulation in such relation to the general ice mass that the particles subsequently became incorporated with it and partook of its later movements. These later movements developed the structures just described which may not have been uncommon in other drift deposits but which are probably seldom so well preserved.

Although the original ice behavior is indicated by these structures it is doubtful whether the observations are of much value toward a better understanding of ice flowage. The ice must have been unusually heavily saturated with these earthy matters, the sands and gravels, and it is probable that differential movements were largely encouraged by their differences of texture.

RESTORATION OF SEYMOURIA BAYLORENSIS BROILI, AN AMERICAN COTYLOSAUR

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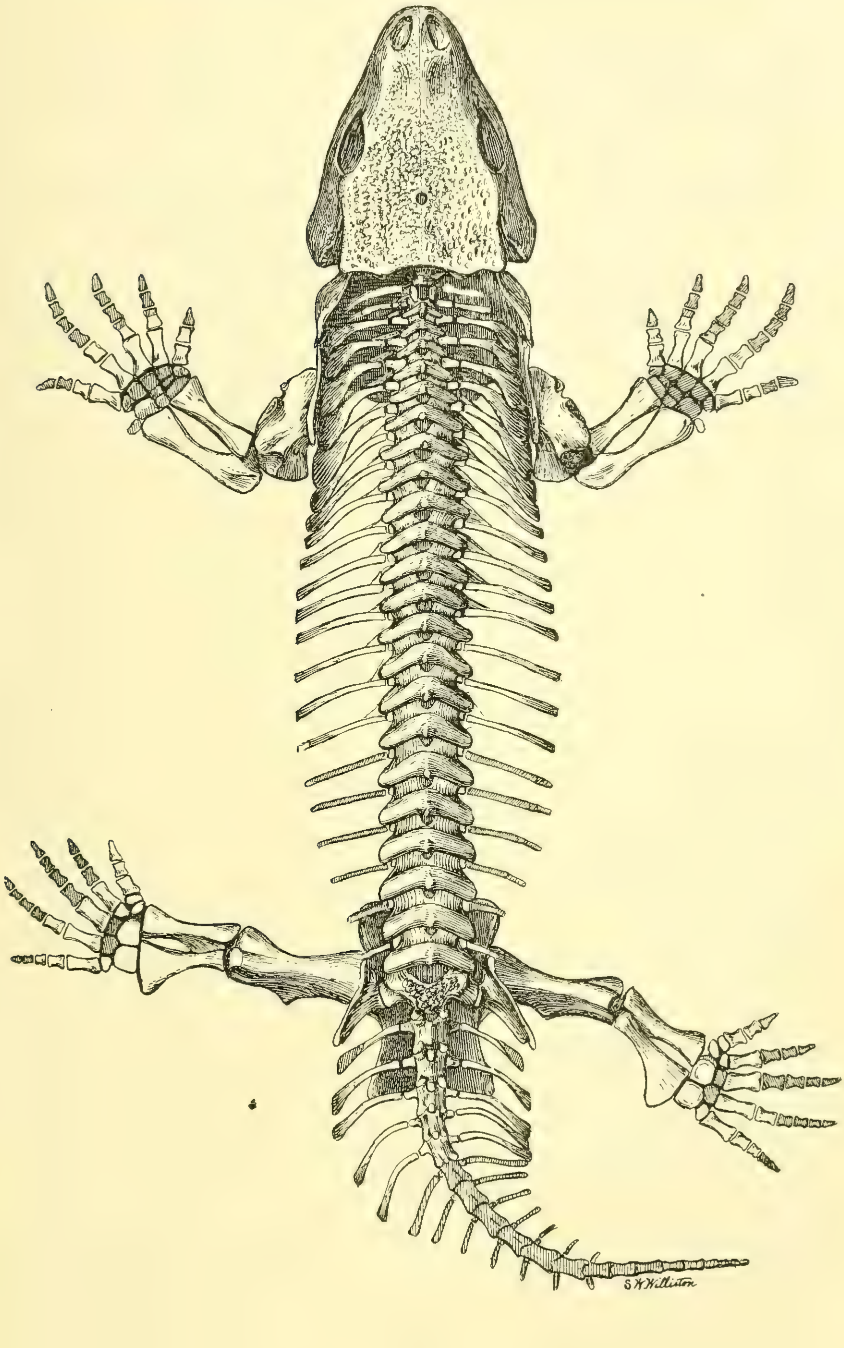
Few Permian vertebrates are of greater interest than the one herewith figured, as restored from a remarkably complete specimen discovered the past year by Mr. Paul C. Miller in the vicinity of Seymour, Baylor County, Texas. The genus and species were originally described by Dr. Broili in 1904 from two imperfect skulls, the clavicular girdle, and a few of the anterior vertebrae and ribs, found on West Coffee Creek, Texas, and preserved in the museum at Munich. Nothing whatever has since been added to our knowledge of the genus, and the appendicular skeleton has remained quite unknown. Of the numerous genera of amphibia and reptilia from the Texas beds not a few are yet but imperfectly known, making it almost impossible to determine many of the isolated limb bones and girdle bones so often found in those regions. The past year I described various limb bones and vertebrae of a small reptile discovered on West Coffee Creek under the name *Desmospondylus anomalus*, suggesting its possible identity with either *Seymouria* or *Pantylus*, especially *Pantylus*, which also is known only from skulls, one of which is in the University of Chicago collections. The two specimens upon which this genus was based are of almost identical size, indicating that the specimens were of adult animals. They prove, however, by comparison with the later acquired specimen, to be congeneric, and of very immature individuals, so immature that they present a number of embryonic characters not seen in the adult specimens, for by the aid of the articulated specimen others of *Seymouria* previously indeterminable have been recognized among the material of the University collections, all from the same region and horizon, the upper or Clear Fork division. And these additional specimens have aided materially in the production of the restoration because of their


S.W.Williston

free condition. The specimen found by Mr. Miller was almost completely inclosed in four pieces of a large clay nodule. All that was visible in the specimen as it lay upon the hillside was a small surface of the cranial table, where a chip had been broken off.

The skeleton, as preserved in the nodule, is almost perfect, save for the large part of the tail, which was inclosed in a protuberance from the main block, and the piece inclosing it doubtless is still to be found in the wash where the scattered pieces were secured. Nearly every bone is in natural articulation, the phalanges for the most part being scattered, some lost, others doubtless yet hidden in the matrix. Furthermore, the bones had suffered almost no distortion or compression. The skeleton was fossilized in a prone position and was somewhat depressed from its own weight. The bones, however, inclosed in the hard, dark, red clay, are rather soft, with a thin, white, cuticular, calcareous layer. So far as possible the skeleton has been laid bare, but no attempt has been made to separate any of the bones, nor could they be separated with safety. The occipital region of the skull, lying above the clavicular girdle, is inaccessible, as are also the posterior ribs, inclosed between the close-lying porrected femora and the vertebral column. Both hind legs are directed forward nearly parallel to the vertebral axis, the feet pulled slightly away from the tibiae and fibulae. The right fore leg also lies close by the side of the body, the hand bones intermingled with the corresponding foot bones. The left fore leg is directed forward. The pectoral girdle lies closely in position, the left side pressed back a trifle, and the pelvic girdle is almost perfectly in place. The skeleton, to the sixth caudal vertebra, measures twenty-one inches. Because of this natural position of the skeleton it has been a matter of little difficulty to figure it in a restored position, the limb bones of other specimens furnishing the proper views in the changed positions. A full description of the form, with detailed figures, will be published later. The figure here given, made with care by myself, will furnish the most of the chief characters of the genus. Those parts unknown or imperfectly known are represented by uniform shading. That the numbers of the phalanges as figured are correct

is practically certain because of the like numbers determined by me in *Limnoscelis;* that the toes were slender is evident from several isolated, unplaceable distal phalanges in the matrix. That the tail could hardly have been longer than is represented, perhaps not as long, is indicated by the taper of the six proximal vertebrae preserved in position, folded down, like a dog's tail, to the extremity of the ischia. Two distal tarsals cannot be seen as covered by the metatarsals; and the carpals cannot be clearly made out.

As a whole *Seymouria* stands lowest in rank among known reptiles, approaching in many ways the contemporary amphibians. This is indicated by the structure of the posterior cranial region, by the extraordinary amphibian ear-notch, by the primitive structure of the vertebral centra, as shown in *Desmospondylus*, by the long, free, caudal ribs, by the possession of a single sacral vertebra, and by the very amphibian-like limb bones and girdles. Indeed, so far as the characters are shown in the figure, there is not a single thing to differentiate the form from an amphibian, unless it be the apparent absence of the cleithrum. Unfortunately the mutilation of the bone in the cranial table prevents the corroboration of the temporal sutures as determined by Broili; but I doubt not that Broili's determinations are correct, showing all the bones found in the temnospondylous amphibians and in similar arrangement, some of which have never been detected in other reptiles. The palate, also, as I make it out, is different from that of other known reptiles, though distinctly reptilian in structure. The pectoral and pelvic girdles are absolutely indistinguishable from those of the contemporary amphibians, save by the more posteriorly directed ilia and the absence of the cleithra, and both of these characters may and probably will yet be found in the temnospondyls.

The suture between the scapula and coracoid is very distinct, quite in the position I have found it in other Texas reptiles and amphibians; and the coracoid is composed evidently of but a single element, the posterior element, the so-called coracoid, remaining cartilaginous through life, as was also the case in *Varanosaurus*. It is because of these facts, observed in several forms, that I am quite convinced the coracoid as preserved corresponds identically

with the coracoid of the lacertilia and rhynchocephalia, that is, it is the true coracoid, and not the procoracoid. To assume that the coracoid of these animals has been replaced *in toto* by another bone, leaving only the supracoracoid foramen, which alone has remained permanent, the bone surrounding it disappearing to give place to another represented by cartilage, in some of the forms at least, and far back of the foramen, is beyond the limits of my credulity, whatever it may be for others.

In the structure of the skeleton of *Seymouria* nothing is more conspicuous than the extraordinary development of the arches of the dorsal vertebrae, forming almost a carapacial protection for the body. That the animal was crawling in habit there would seem to be no doubt, notwithstanding the position in which the hind legs were found—a position quite the same as that of the type specimen of *Limnoscelis*. No indications of ventral ribs are preserved and I think it may be said with absolute certainty that the creature possessed none in life. On the other hand, scattered through the matrix were numerous small flakes of bone, always isolated. They may indicate osseous scutes. The teeth of the creature are long and slender, utterly useless for the seizure and retention of large prey. I think it very probable indeed that its food consisted in large part, probably wholly, of the smaller invertebrates, cockroaches, land mollusks, worms, etc., and that in habit *Seymouria* was not unlike the modern land salamanders, slow and sluggish in movement, hiding under fallen and decaying vegetation in low and damp places.

The American cotylosaurs, more especially the Diadectidae, Limnoscelidae, and Seymouriidae, show marked resemblances in many ways to the contemporary amphibians, in their short legs, broad feet, enormous humeral entocondyle, digital fossa of the femur, pronounced adductor crest, as well as girdles; but I do not believe that these resemblances were so much the result of phylogeny as of convergent evolution, the adaptation to similar environmental conditions and similar habits. *Araeoscelis* alone among the known American Permian reptiles had a very slender body and delicate, slender legs, adapted for climbing, or at least for swift-moving upland habits. That there were many other

reptiles in Permian times of similar structure and habits is evidenced by *Kadaliosaurus*, among others. And all these must have come from a common amphibian ancestry, so far back in Carboniferous times as to permit great structural diversity among both the reptiles and the temnospondyls in early Permian times, too great to warrant the assumption that all similar characters in the two classes are the result of heredity.

The relationships of *Seymouria* are, on the one hand, closest with *Limnoscelis*, on the other with *Labidosaurus*, but differing so markedly from both as to merit a co-ordinate independent position for the genus, which I prefer to call of family value—the Seymouriidae.

GEOLOGIC AND PETROGRAPHIC NOTES ON THE REGION ABOUT CAICARA, VENEZUELA[1]

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In the winter of 1908–9, the writer carried on some independent studies along petrographic and geologic lines, in the interior of Venezuela, choosing for his field of investigation the region immediately west of the so-called "El Caura District," at the famous bend of the Orinoco, and mapping an area of 1,400 sq. km., which was hitherto very little known. While the general results of this survey have been summed up elsewhere,[2] it is on the main geologic and petrographic features of the region that the writer wishes to offer the following observations.

GEOLOGIC STRUCTURE

I. THE BED ROCK

The bed rock consists of a series of granites and gneisses which, wherever they come to the surface, show a predominance of the gneiss over the granite. These granites and gneisses rise from the bottom of the Orinoco channel; constitute the base of many of the islands; are exposed in the banks of the river, particularly in the dry season; and back from the river form the bulk of the "Cerros." These cerros are hills and small mountains which rise above the plain of the sabana. In general they increase in height in proportion to increasing distance from the Orinoco, and may be regarded as outliers of the Guiana mountain system lying to the south. These cerros are probably to be considered as portions of the great series of granites and gneisses which have most effectively resisted disintegration, partly because a skeleton of numer-

[1] The writer desires to express at this place his high obligations to Professor B. K. Emerson of Amherst College who was kind enough to have the petrographic microscopes of Smith College, Northampton, Mass., placed as his disposal.

[2] Petermann's *Geogr. Mitteilungen* (1910), Bd. 56, v; *Geographen Kalender* (1909), 221.

ous veins and dikes cutting each other in all possible directions traverses them.

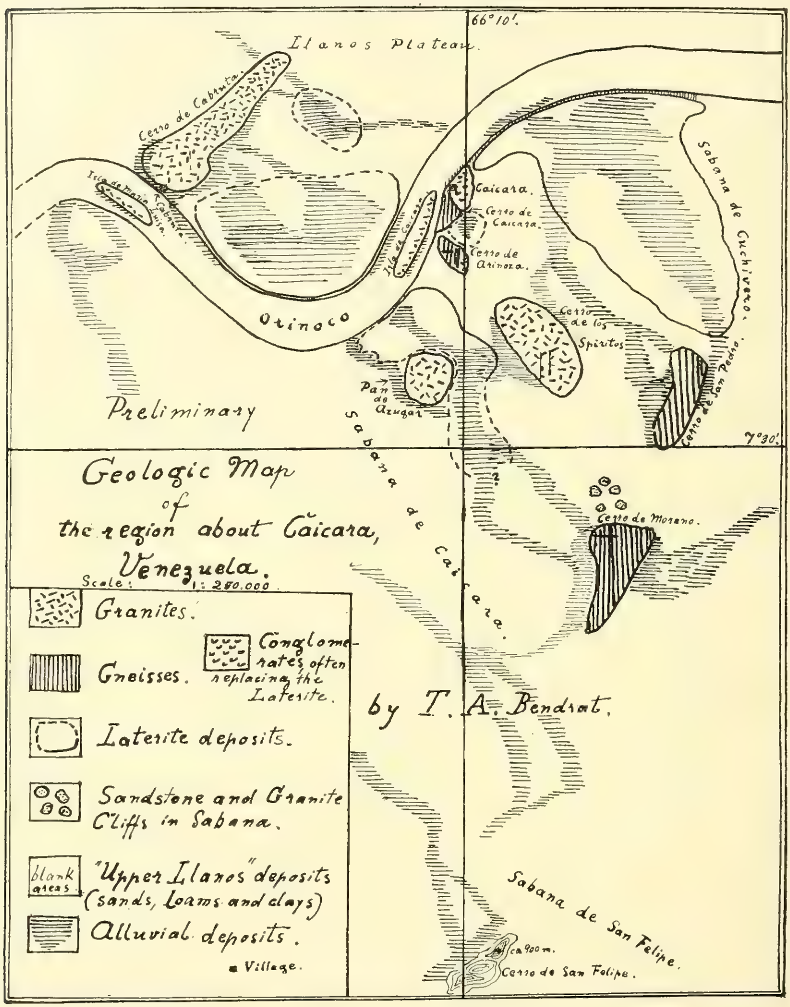
An extended survey of the shores of Isla de Caicara, opposite the village of Caicara, showed that the bed rock of this island is a medium-grained granite of comparatively firm texture, which is drab colored in fresh breaks, but which weathers to a purplish tint. This rock shows cleavage planes extending north and south, and east and west.

The cliffs exposed on the Caicara side of the stream by the falling of the Orinoco during the dry season consist of medium to fine-grained gneiss, whose laminations run either N.N.E.–S.S.W., or E.N.E.–W.S.W. Quartz veins, varying in thickness from three to five inches, cut the gneiss in a general N.W.–S.E. direction. It was on the surface of one of these rocks, about 1 km. north of Caicara, that the writer discovered what, considering the latitude, would seem a very curious phenomenon. This consisted of three grooves, about five inches long and one-eighth inch deep, which run perfectly straight, one N. 80° E., and the two other S. 80° E. They show a striking resemblance to glacial striae, but this does not exclude the possibility that they may have been produced by man, as in close proximity a series of the so-called "petroglyphics" was found, the grooves of which, however, were considerably deeper and wider. The surfaces of the rocks on which the grooves were observed were considerably smoothed, as were the rocks of the banks of the Orinoco, but this might be due to the effects of the currents.

The distribution of the granite and the gneiss in the hills and ridges north of Cabruta and south and southeast of Caicara also plainly reveals the prevalence of the gneiss over the granite, for, with the exception of Cerro de Cabruta, north of the Orinoco, and Cerro de los Spiritos, the lower portion of Cerro de Arinoza, and possibly the whole of Pan de Azugar, all the cerros consist of gneiss (see map, Fig. 1).

The Cerro de Cabruta, rising abruptly at its southwestern terminus from the waters of the Orinoco to a height of about 290 meters above sea-level, trends, for a distance of about 12 km., in a N.E. direction, and gradually falls off toward the llano plateau.

The cerro is entirely made up of a coarse-grained feldspathic granite, which weathers to a dull reddish purple, and in fresh cuts has a



For geographic map see "Petermanns Mitteilungen" 1910, plate 46.

Fig. 1

yellowish-white color. The yellow predominates over the white. Toward the top, the granite becomes more and more quartzose,

while at the same time the quartz veins become more and more frequent. Some of these quartz veins strike parallel to the general cleavage planes; that is N. and S., while others run E. and W., and W.N.W. and E.S.E. The disintegration of the granite by means of exfoliation was most strikingly exhibited on the top. At one place a dike of gray to bluish-white quartz cut the granite in a direction N.N.W. and S.S.E., which most probably determined the initial direction of the southwestern spur of the cerro. Along the line of contact, the granite seems to have become changed locally into gneiss with lamination in a direction N.N.W. and S.S.E. This was, however, the only instance of a gneissic phase observed in the bulk of the granite.

Of the series of cerros on the southeast side of the Orinoco, the Cerro de Caicara comes first and lies immediately south of the village of Caicara. It rises to a height of 127 meters above sea-level and extends about 2 km. to the south, along the bank of the stream. It consists entirely of a more or less fine-grained gneiss of light color, but on weathering becomes a dark purple. At different levels the gneiss is highly charged with various grades of iron oxide, which exhibit beautiful shades of color, ranging from tan through ochre yellow to a dark bloody red. The direction of lamination is, in most cases, parallel to the general strike of the rocks.

About 3 km. south of Caicara lies the Cerro de Arinoza, which attains a height of 146 meters, while its foot is 71 meters above sea-level. Only the lowest levels of this hill consist of a close-grained quartzose granite such as was encountered in the Cerro de Cabruta. The structure of this granite is in places pegmatitic and the cleavage planes run N. and S., and E. and W., as do quartz and pegmatite veins. Higher up in the slope, however, the granite yields to a medium-grained gneiss, the laminations of which run S. 20° E. and dip at an angle of 27° to the northeast.

The Cerro de los Spiritos is situated about 5 km. east of Pan de Azugar, and nearly 8 km. S.S.E. of the village of Caicara. About 200 feet high, it trends in a general N.W.–S.E. direction for over 5 km. With a possible exception of Pan de Azugar, as indicated above, it is the only cerro southeast of the Orinoco within

the scope of the region under discussion which is entirely composed of granite. It is of the coarse-grained feldspathic type and exhibits joints which run pronouncedly N. and S., E. and W., and N.W.–S.E., and in no other direction. The backbone of the hill is a quartz dike from 3 to 5 feet wide, which runs along the southwestern flank of the hill in a N.W.–S.E. direction. Assays made of samples from this dike reveal traces of gold. Other quartz dikes run parallel to this one as well as at right angles to it, while near the top a dike of pinkish felsite about 2 feet thick and running E.–W. stands out prominently from the surrounding coarse-grained granite, which assumes a rather hornblendic aspect in the upper levels. The flanks of the cerro, where slopes are gentle, and only occasionally steep, are dissected by gullies and ravines running parallel to the main quartz dikes in the main.

About 26 km. S.S.E. of Caicara the Cerro de Morano rises above the plain of the sabana in two distinct knobs which have heights of 375 and 396 meters respectively above sea-level. Its topographic outlines seem to be determined by two main quartz dikes, the more prominent one running N. and S., constituting the backbone of the cerro. Approaching the cerro from the north, one encounters knobs and cliffs emerging from the sabana, which consist of purplish weathering, coarse-grained feldspathic granite, occasionally highly charged with iron oxides, and at places overlain by limited (in size) "banks" of ferruginous coarse-grained sandstone. But the bulk of the cerro itself is made up of hornblende gneiss, which ranges from fine to coarse grained. The average direction of lamination is N. and S., and N.W. and S.E.

2. THE SABANA DEPOSITS

In dealing with the deposits of the sabana, above which rise the isolated cerros just described, one must distinguish between the so-called "Laterite" deposit and what Dr. S. Passarge terms "Upper Llanos" deposits.

1. *The "Laterite" deposit.*—This deposit is a concentration of iron oxide in a series of more or less fine and soft clays of a light gray color. Deposits of this class have been found by Dr. S. Passarge along the banks of the Cuchivero as well as the Caura,

and by the writer overlying the gneisses on the banks of the Orinoco. As long as the deposit is under water or is still charged with water after the streams have fallen during the dry season, it is very pliable; but as soon as it becomes dehydrated, it turns extremely hard and takes on the aspect of a clay ironstone. It has been

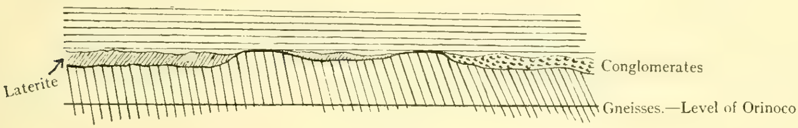


FIG. 2

called "Laterite," and likened to the German "Zellinger Brauneisenstein." The only true laterite portions form the upper part of the clayey mass or are segregated from this. The clays are in many places marbled by a more or less intense red. The deposit directly and unconformably overlies the gneissic or granitic bed rock. The deposit is not continuous and is frequently replaced by a conglomerate, cemented by iron oxide (see Fig. 2). It occurs inland as well as along the Orinoco.

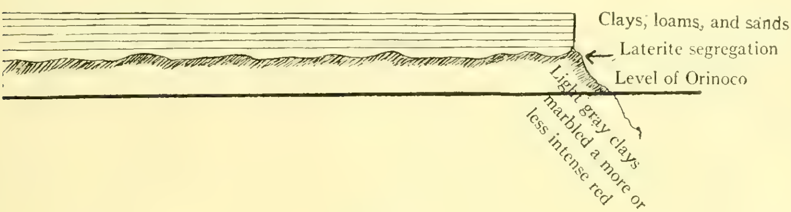


FIG. 3

2. *The Upper Llanos deposits.*—The Upper Llanos deposits which, as a rule, unconformably overlie the "laterite," wherever they have not been removed by erosion, may be said to consist of the following three members: (1) A whitish or yellowish clay which exhibits yellowish-brown cell structure, rich in iron; (2) loams of various nature; (3) sands of different fineness and color.

Their interrelation changes with the locality and so do their respective horizons. They constitute the upper portions of the islands, as well as the upper terraces at an elevation of 50 feet, approximately, above the average level of the lower terraces, and

finally, the sabana itself. They lodge between the rocks of the granites and gneisses, wherever these come to the surface, filling in interspaces. The loam becomes very pliable and soft during the rainy season, so much so as to allow mud turtles to plow furrows from half a foot to a foot deep in it. Local torrents sometimes carve channels down to the underlying laterite. The walls of these channels become extremely indurated during the dry season, rendering traveling across the sabana under such conditions laborious, especially where there are no roads or paths available.

PETROGRAPHY OF THE GRANITES AND GNEISSES THAT CONSTITUTE THE CERROS IN THE SABANA ABOUT CAICARA

1. THE GRANITES

The granites of the region under consideration comprise those of the Cerro de Cabruta, the Cerro de los Spiritos, and those at the base of the Cerro de Arinoza. A detailed microscopical study of specimens taken from different levels shows that in all three cerros the type of granite is essentially the same. This statement, however, has to be modified in so far that, at one end of this elliptic area, the granite is decidedly leukocratic while at the other it is melanocratic. While the Cerro de Cabruta consists of a more or less pronounced quartzose granite in its upper levels and its top, the Cerro de los Spiritos reveals a decided predominance of hornblende in the granite of its top.

Though described here in general terms as granite, this rock is more correctly designated as quartz monzonite porphyry. Its ground mass is made up of more or less angular or subangular crystals of quartz and feldspar through which the leading minerals are sprinkled as phenocrysts. These phenocrysts are quartz, which sometimes predominates over the feldspars, occasional orthoclase associated with, or replaced by, microcline, the soda-lime and lime-soda feldspars albite and labradorite, and finally biotite, associated with or entirely replaced by hornblende.

Quite a number of quartz and feldspar phenocrysts show enlargement by secondary growth as revealed by zonal extinction or by a more or less faint ring of dark material, apparently representing a coating of the original grain.

The frequent occurrence of a micro-pegmatitic texture suggests conditions in the original magma that favored a simultaneous crystallization of the quartz and feldspar.

Of the feldspathic minerals those of the soda-lime group apparently prevail over the orthoclase (not so much over the microcline), and among them labradorite is the one most frequently found.

The biotite occurs in lath-shaped crystals and in shreds and flakes, the amphibole mostly with prismatic outlines, and only occasionally in cross-sections. It was in such a cross-section that an intergrowth of biotite and amphibole was observed, the former penetrating the latter, clearly demonstrating their contemporaneous development. Apatite and titanite occur as inclusions in the biotite, while the amphibole contains apatite and magnetite. Microlites of biotite and apatite needles have been observed in feldspar, while quartz carries magnetite, apatite, and occasionally zircon. In cavities within the quartz liquid inclusions are sometimes present. Titanite is also found free in wedge-shaped crystals, and considerable garnet, in more or less complete crystals, occurs. Secondary minerals are calcite, which might have been derived from some of the feldspars, and chlorite, which apparently has come from the biotite.

Wavy extinction in quartz and feldspar; bending, breaking, and slicing of feldspar and biotite; granulation of feldspar and occasionally of quartz; and the complete crushing of titanite crystals strongly suggest dynamic stress and shearing.

The occurrence of looped grains of orthoclase, and the more or less advanced decomposition and the decoloration of a considerable percentage of the biotite indicate katamorphic action, most probably by descending waters, while the secondary growth of minerals, involving zonal structure, and the formation of veinlets, where crystals were broken, tell rather of the anamorphic activity of ascending solutions.

2. THE GNEISSES

The gneisses of the cerros in the sabana of Caicara comprise those of the Cerro de Caicara, Cerro de Arinoza, with the exception of its base, and those of the Cerro de Morano. A micro-

scopic analysis of thin sections of samples taken from all levels of these cerros, and a comparison of their composition, texture, and fabric, tend to lend much weight to the assumption that the gneiss throughout belongs to one and the same unit, as it was one and the same type of rock we had to deal with in the granites. This statement is, however, not intended to exclude the possibility of local phases representing gradation and variation.

Like the granite, the gneiss is porphyritic. In a ground-mass commonly of angular or subangular grains of quartz, with rather fringed and dentated outlines, and of feldspars, especially microcline and plagioclase, which usually are arranged with their longer diameters parallel or slightly inclined to the plane of rock-cleavage, are imbedded phenocrysts of pegmatite, microcline, albite, labradorite, and biotite. All of these minerals, with the exception of the biotite, are more or less allotriomorphic. Microcline seems to take the place of orthoclase to a great extent, wherever the latter is not intergrown with quartz, and we might say that the predominance of microcline and pegmatite constitutes one of the main features of this gneiss. Another feature is the frequent occurrence of crossed lamellae in the plagioclases and a marked tendency to form rather broad lamellae.

Of the feldspar and quartz the former is in excess. Among the ferro-magnesian minerals, biotite, in phenocrysts of lath-shaped form and in flakes, seems to be almost the only representative. Hornblende is very seldom encountered, though in one instance it was found intergrown with biotite.

Of accessory minerals an occasional crystal of pyroxene is encountered, while magnetite and hematite are more frequently met with. Garnets are not uncommon and wherever they occur they are idiomorphic. Chlorite is present most probably as a decomposition product from biotite and hornblende.

As regards inclusions in the different minerals, magnetite occurs in feldspars, arranged more or less parallel to the plane of parting, and in quartz where it occurs as a cloudy matter and in dendrites. Of other inclusions may be mentioned zircon, apatite, titanite, and tourmaline (?) in quartz, and very fine glassy particles in the plagioclases.

The gneisses, even more than the granites, exhibit overwhelming evidence of metamorphism, during, as well as since, their formation. Among the evidences of stress and shearing, may be mentioned: The wavy extinction in quartz and feldspar grains; the bending of biotite; the differential bending and anastomosing of the lamellae of feldspars; cracks and fractures parallel or normal to the plane of parting in biotite; the slicing of crystals of pegmatite and microcline; the breaking of crystals of feldspar and biotite and displacement of the broken parts by miniature faulting; a granulation zone about grains of pegmatite.

A gneissoid texture is given to the rock by the more or less parallel arrangement of the longer axes of the minerals to the plane of schistosity of the rock.

The dissolving agency of descending waters is shown by the schiller structure of some plagioclases, the cloudy appearance of other feldspars, and the decomposition of some of the magnetite, biotite, and hornblende. The anamorphic agency of ascending waters is indicated by secondary growth of quartz, plagioclase, and biotite; by the cementing of cracks and fissures, and by the formation of veinlets by segregation from the same mineral or by infiltration from some other source.

3. THE VEINS AND DIKES IN THE GRANITES AND GNEISSES

The writer profoundly regrets that he did not have time to examine more closely the veins and dikes of the cerros about Caicara, as a more detailed and special study of these veins and dikes most probably would have brought out different sets, as indicated by uniformity of strike and dip and of composition, and might have shown something in relation to the nature and the succession of the dynamic movements which the gneisses and the granites, individually or together, have undergone.

While the writer is far from attaching any special significance to it and deducing any particular law of succession from it, because of the limited material on hand, it is nevertheless a peculiar fact that all of the more prominent quartz veins and dikes encountered have a strike magnetic N.–S., while all the pegmatite veins and dikes strike E.–W. Near the summit of Cerro de Morano a vein

of fine-grained amphibolitic gneiss, varying in thickness from two to three feet, strikes N.–S. A few feet below the top of Cerro de los Spiritos a felsite vein about one foot thick extends E.–W. and stands two feet above the surrounding coarse-grained granite, so that from a distance it has the appearance of the remnant of a brick wall. A microscopic investigation showed that its main constituents are quartz and plagioclase in nearly equal proportions, while some dark-brown and yellow biotite occurs as an accessory mineral. A microscopical examination of the N.–S. quartz veins shows that they are made up of very small grains of quartz with dentated margins in most cases and most intricately interlocked; of bronze-brown to dark-green amphibole in irregular patches; occasional tourmaline in radiate aggregates; some garnets, and some magnetite.

In concluding, the writer wishes to remark that it would be of great interest to ascertain the geologic and petrographic nature of other outliers in those waste plains that approach the Orinoco from the S. and from the E., as well as the character of the rocks that make up the bulk of the Guiana mountain system, in order to bring out facts that would bear on the relations of those cerros to this, most probably, Archaean center.

THE AGE OF THE TYPE EXPOSURES OF THE LAFAYETTE FORMATION[1]

EDWARD W. BERRY
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The following brief communication is devoted to showing the Eocene age of the type-sections of the Lafayette formation in Lafayette County, Mississippi, and also at certain additional localities in northern Mississippi and southwestern Tennessee where fossil plants have been collected by the writer.

The term Lafayette formation has come in late years to be widely used by American geologists and the volume of literature devoted to its consideration is by no means inconsiderable.

It is not necessary in the present connection to recite the history of the study of the deposits which have been referred to the Lafayette. It will suffice to recall that the name was proposed by Hilgard[2] in 1891 for those deposits so elaborately described in his *Geology of Mississippi*[3] as the Orange Sands, and typically developed in Lafayette County. Chief among the students of the Lafayette was W J McGee who extended their occurrence from Mississippi to Pennsylvania on the one hand and as far as Texas on the other.[4]

The writer is not concerned in the present brief note with those deposits in the various Atlantic and Gulf states which have been referred to the Lafayette formation by different geologists. In certain limited areas, however, reliable data have been obtained which may appropriately be announced in the present connection. Thus in the vicinity of Columbus, Georgia, materials classed as Lafayette are Cretaceous in age. Other materials referred to

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] Hilgard, *Amer. Geol.*, VIII (1891), 130.

[3] Hilgard, *Rept. on Geol. and Agr. of Miss.* (1860), 5–46 (the name Orange Sand was that of Safford, 1856).

[4] McGee, *U.S. Geol. Surv., 12th Ann. Rept.*, Part I (1891), 347–521.

the Lafayette in the vicinity of Glen Allen, Fayette County, Alabama, should be assigned to the Tuscaloosa. In several sections across the Cretaceous of northeastern Mississippi in the latitude of Tupelo and Booneville, the Lafayette cover in all observed exposures resolves itself into the weathered beds of the Cretaceous. The same statement is true in the writer's judgment of the great cut near Cypress, Tennessee, on the Southern Railway. This whole section was included in the Orange Sand by Hilgard and figured diagrammatically on p. 16 of his *Geology of Mississippi*, though it was subsequently shown that the basal part was Ripley Cretaceous. The writer visited this exposure during the past season and failed to see any reason for not including it all in the Ripley. Furthermore, at a large number of localities throughout the Mississippi embayment area, Pleistocene terrace deposits have been referred to the Lafayette formation.

During 1910 it was the writer's privilege to spend considerable time in the collection of fossil plants in Lafayette County, Mississippi, and northward as far as Cairo, Illinois. It might be added parenthetically that five previous field seasons spent, for the most part, along the inner margin of the coastal plain from New Jersey to Mississippi have afforded considerable opportunity for observing the so-called Lafayette.

It has been commonly supposed for some years back that the Lafayette formation of Mississippi and western Tennessee was not a unit, since remains of the so-called eolignitic flora have been reported from time to time as occurring in it at numerous localities. It has been assumed, however, that these plants came from the Eocene clays beneath overlying Lafayette materials. While at most of the localities visited during 1910 the Wilcox clays with leaf impressions are overlain by reddish sands of no considerable or uniform thickness, this is not always the case, as is well shown by one of the exposures along the Illinois Central Railroad just north of Oxford, Miss. The outcrops in these railroad cuts, a number of views of which, from photographs by the writer, are here reproduced, were the type-sections of Hilgard's Orange Sands and Lafayette. Here as at every other locality where the writer collected plant fossils in Lafayette and Marshall counties, Missis-

sippi, and in Fayette and Hardeman counties, Tennessee, there is no unconformity between the Eocene Wilcox leaf beds and the supposed Lafayette if the latter be restricted to the few upper feet of weathered sands.

In order that there might be no room for doubt but that the Oxford exposures furnish the type-sections for the Lafayette, Dr. McGee has kindly prepared the following letter covering this point, at the request of Dr. T. Wayland Vaughan, geologist in charge of the coastal plain investigation for the U.S. Geological Survey:

[Copy]

March 1, 1911

MY DEAR DOCTOR VAUGHAN: In further reply to your oral inquiry: On looking up the records, I find it clear that the type locality in Lafayette County, Mississippi, from which the Lafayette formation received its current designation, is Oxford, the site of the state institution of learning with which Dr. Hilgard was long and honorably connected; and that the type-section is the exposure in the Illinois Central Railway cut at Oxford shown by Dr. Hilgard in *Geology and Agriculture of Mississippi* (1860), p. 6, in the drawing reproduced by me in "The Lafayette Formation" (*Twelfth Annual Report, U.S. Geological Survey*, Fig. 58, p. 457). This section was in good condition for examination in 1891, and was re-examined as the type-section by Dr. Hilgard, the late Dr. J. M. Safford, Dr. Eugene A. Smith, Dr. Joseph A. Holmes, Professor Lester F. Ward, Mr. Robert T. Hill, and myself, jointly, and was still in good condition in February, 1910, when re-examined by Dr. E. N. Lowe, state geologist, and myself, as the type-section of the formation.

Yours sincerely,

(*Signed*) W J MCGEE

In the exposures at Oxford the deposits are a unit with every gradation from unweathered materials below to oxidized and more or less ferruginous sands above. Nowhere in this region is there a line of unconformity or a pebble bed to mark the supposed time interval extending from the early Eocene to the Pliocene. The change in color of the materials when marked at all is at varying levels and is due apparently to the depth to which the ferric oxide in the sands has been dehydrated. A quotation from McGee's longer paper on the Lafayette will make it clear that he did not recognize any unconformity between the leaf-bearing clays now ascertained to be Eocene, and the overlying sands. On pp. 458, 459, he says:

Several competent geologists familiar with the Lignitic in Mississippi, Alabama, Tennessee, and Arkansas are disposed to refer the leaf bearing clays to that formation on the ground of lithologic resemblance. If this reference be just, then the thickness of the formation may be less than that assigned by Hilgard at Oxford and Johnson at Holly Springs, and even the exposed thickness at La Grange may include an unknown amount of the protean Lignitic deposits though no demarcation has ever been found.

At one of the Oxford exposures, previously mentioned, the Eocene clay lens is almost at the surface and overlies "typical

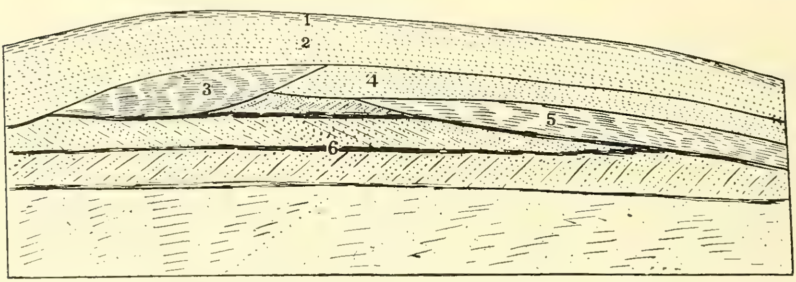

Fig. 1.—Diagram of exposure furnishing fossil leaves in the type area

Lafayette materials." This section is shown diagrammatically in Fig. 1, and may be described as follows:

SECTION EAST OF I.C.R.R. ½ MILE NORTH OF OXFORD STATION

No.	1.	Brown loam	1– 2 ft.
	2.	Rather coarse brown stratified sand	4– 6 "
	3.	Lens of gray to white siliceous clay, carrying abundant leaf impressions	0– 5 "
	4.	Stratified orange sand	2– 3 "
	5.	Lens of gray siliceous clay, with poorly preserved leaf impressions	0– 4 "
	6.	Coarse brown cross-bedded sands separated by ferruginous indurated bands 1 to 3 inches in thickness. Replaced horizontally by pinkish or grayish buff finer sands	10–12 "

Fig. 2 is from a photograph of this outcrop, the fossil plants having come from near the top of the exposure at the "nose" just below the small tree shown in the center of the picture. The clays at this point are siliceous and do not contain an extensive flora, and the collections consist largely of the abundant remains

FIG. 2.—View showing the plant locality one-half mile north of the depot, Oxford, Miss.

FIG. 3.—View showing ferruginous cross-bedded sands just north of the plant locality.

of a *Panax*-like form and a fan palm identical with what Lesquereux called *Sabal grayana*. The latter was originally described from the Lignitic[1] and the former, while apparently new, is closely allied to early Tertiary forms from southern Europe. Few forms abundantly represented may be taken as indicating that the plants were not drifted into the basin of sedimentation from a

FIG. 4.—View showing the type-section of the Lafayette just south of the depot at Oxford, Miss.

distance but that they grew in the immediate vicinity and that the shallow waters of the Mississippi gulf in Wilcox time were not marine in this latitude. This is also indicated by the impressions of Unios in this same clay lens. At some of the other plant localities visited, as for example that at Holly Springs and Early Grove in Mississippi and at Grand Junction and La Grange in Tennessee, all of which are specific Lafayette localities of McGee, the fossil floras are more varied and consist of species of Cercis, Laurus,

[1] Lesquereux, *Proc. Amer. Philos. Soc.*, XIII (1869), 412, Pl. XIV, Figs. 4–6.

Ceanothus, Banksia, Dryophyllum, Sabal, Ficus, Dalbergia, Nerium, Terminalia, and perhaps one hundred additional forms, including even flowers and Acacia-like pods, all unquestionably of Eocene age and closely paralleling the Eocene floras of southern Europe. Furthermore these Eocene forms are all of them contained in beds absolutely inseparable from the surficial more or less

FIG. 5.—View showing the character of the materials referred to the Lafayette, one mile north of depot, Oxford, Miss.

oxidized sand which a forlorn hope might lead one to retain as representing the Lafayette.

It must not be supposed that there are no surficial deposits in this general region. The present communication is merely intended to show that certain fossiliferous sections including the type-section of the Lafayette and probably all of the Lafayette in Lafayette County, Mississippi, are of Wilcox Eocene age. A possible objection to the foregoing conclusion might be that these floras upon which it is in part based are really Lafayette floras. This is

utterly impossible. In the first place it would mean that the balance of the leaf-bearing Wilcox is of Lafayette age since the two have a considerable number of species in common. McGee seems to have had some premonition that the fossil plants when studied would not bear out his conclusions since he writes:

> The testimony of the plant fossils is of course only suggestive; for not only is the identification incomplete, but there are thus far no means of comparing the stages in evolution of plant life in the upper Missouri and Rocky Mountain regions and the lower Mississippi region respectively; it can only be said that in the one region the geography was repeatedly revolutionized in such way as greatly to modify climatal conditions, while in the other the geography has undergone only minor changes of such character as not to modify climate, so that the flora has undoubtedly persisted in the remarkable fashion suggested by the present existence of Laramie or Lafayette plants in Louisiana.

This may be dismissed as a specious argument, for it can readily be shown that no post-Miocene floras of the northern hemisphere contain the types which are prominent in this flora. On the other hand the climatic changes have been considerable, even the Pliocene flora in this area of supposed slight change containing species no longer present in the region or even in North America.

In the second place the flora is closely allied to European floras of unquestioned Eocene age, more especially to that described by Saporta from France, and in its *tout ensemble* it denotes climatic conditions very different from those which could possibly have existed in Lafayette time.

There are high-level gravels in northeastern Mississippi and in northern Tennessee and beneath the loess along the Mississippi bottom ("delta") as well as at various points along the Atlantic Piedmont border. Whether these are river gravels of various ages or whether we are dealing with the remnants of a high-level early Pleistocene sea terrace is not clear, although a combination of the two is the probable solution.

THE RIPPLES OF THE BEDFORD AND BEREA FORMATIONS OF CENTRAL AND SOUTHERN OHIO, WITH NOTES ON THE PALEOGEOGRAPHY OF THAT EPOCH[1]

JESSE E. HYDE
Columbia University

THE BEDFORD AND BEREA FORMATIONS

The Bedford and Berea formations are respectively the lowest and second lowest members of the Waverly series of Ohio. They were formed either at the close of the Devonian or at the beginning of the Mississippian period. They can be traced continuously across the state along the outcrop, from the Pennsylvania line on the northeast to the Ohio River on the south and over broad areas under cover to the eastward. The Bedford is almost entirely a shale formation usually about 100 feet thick; the Berea is a sandstone roughly from 20 to 150 feet thick.

In northern Ohio, the Bedford is largely an argillaceous shale with sandstones present locally, the Berea a coarse, feldspathic sandstone; the two are separated by an erosion plane.[2] In southern Ohio the Bedford consists of interbedded sandstones and shales, the former sometimes greatly in excess, the Berea of similar sandstones with limited quantities of shale. The sandstones in both are fine grained and of exactly the same type while between the two there is a transition zone. It is now becoming evident that the geological history of these beds has been quite different on opposite sides of the state, although the relation of the succession in one area to that in the other is not yet known. The Berea of southern Ohio is only a phase of the Bedford of the same region, while that of northern Ohio is wholly distinct from the Bedford and probably from the southern Ohio Berea. However, as a sandstone formation, it is continuous across the state.

[1] Published by permission of the State Geologist of Ohio.

[2] Charles S. Prosser, manuscript.

In the area under immediate consideration, central and southern Ohio, the Bedford is from 90 to 100 feet thick, the Berea from 5 to 40 feet thick. In Scioto County on the Ohio large amounts of sandstone are found in the Bedford, but this diminishes to the northward so that there is much more shale in Pike and Ross counties, while in Franklin County there is practically no sandstone, except in the upper 10 feet where very thin layers appear in profusion. In Pike and Ross counties the sandstones are frequently limy. When present, the sandstones are in beds from a few inches to two or three feet thick, but the "shale" beds intervening between such beds, often several feet thick, are largely made up of very thin, hard, platy sandstones of which there may be 12 or 18 in a foot.

Exactly the same type of sandstone is found in the Berea of central and southern Ohio as in the Bedford, except that the lime disappears. In fact the Berea is distinguished from the Bedford of the region almost solely by the rather abrupt diminution in the amount of "shale." These shale beds are found to some extent in the lower part of the Berea and, just as in the Bedford, they carry the numerous, thin, platy sandstones. In other words, the lithological change from the Bedford to the Berea was almost wholly one of amount and not of kind of material.

THE OCCURRENCE OF THE RIPPLES

Ripples are seldom noted in the lower part of the Bedford. In southern Ohio they appear rather gradually near the middle, and throughout the upper half of the Bedford and most of the Berea they are present, sometimes in astonishing abundance. The surface of each of the very thin lamellae of sandstone is rippled, as well as of the thicker beds. In central Ohio they appear first in the thin sandstones at the top of the Bedford, but are confined almost wholly to the Berea. In central Ohio and as far south as Pike County, the ripples gradually disappear in the upper part of the Berea and they may be absent entirely in the upper 10 or 15 feet, which also may become slightly coarser.

Many localities can be found, especially in Pike County, where the streams have cut into the Berea grit or the upper part of the

Bedford, and flow for some distance over a rock floor composed of the strata of these formations. Bed after bed is exposed in descending order, each with a beautifully rippled upper surface, and where the stream cuts through one of the "shaly" beds as many as 12 or 18 may be encountered in a vertical thickness of one foot, each ripple-marked. The parallelism of these ripples is most strikingly shown where the gradient is such that the stream descends gently across such a series, each of the surfaces forming the creek bed for a distance, to be superseded presently by the next layer lower down.

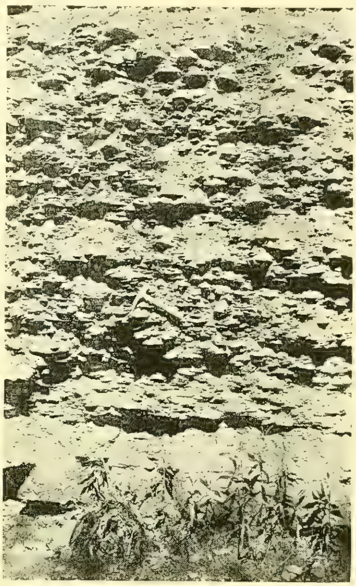

FIG. 1.—A portion of the upper part of the Bedford in the D.T. and I.R.R., cut southeast of Waverly, showing the many thin platy sandstones which largely make up the shaly portions of the formation. Each is rippled. Sometimes only the crests of the ripples are preserved as a series of lenses. The thicker sandstones are not present in this outcrop.

REVIEW OF PREVIOUS WORK

E. B. Andrews in 1870 first noted that the ripple-marks in the vicinity of Buena Vista trend in a northwest-southeasterly direction.[1] The formation in which they occur is not indicated and the context suggests that they are in the "city ledge" of the Cuyahoga, but they can only be in the Bedford and Berea, since ripples do not occur in the other.

Dr. Edward Orton, Sr., next called attention to the constancy of direction of these ripple-marks in Pike County. In his account of the geology of Pike County he says "the surfaces of successive layers, for many feet in thickness, are often covered with ripple-marks, all of them holding the general direction of north 53° west,

[1] *Geol. Surv. Ohio*, Rept. Progress [in 1869] in Second District, ed. of 1870, p. 68; ed. of 1871, p. 72.

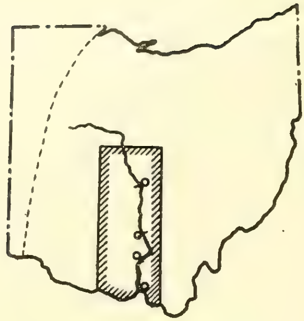

FIG. 2.—Outline map of Ohio showing area represented in large map of ripple directions, and general direction of the Cincinnati axis in Ohio (dotted line across western part).

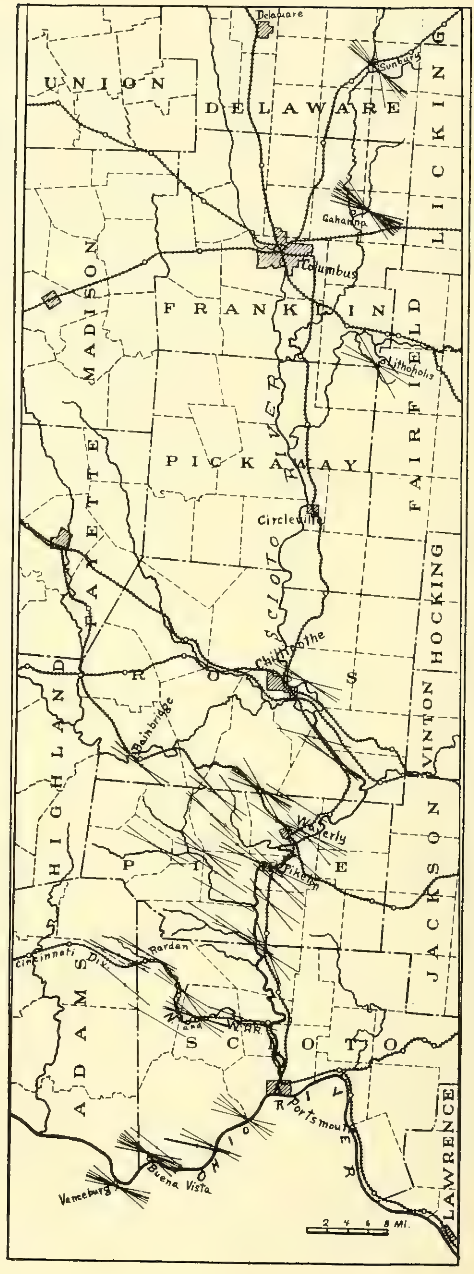

FIG. 3.—Map showing the ripple directions in the Bedford and Berea formations of central and southern Ohio

or south 53° east."[1] In a footnote to the last, he states that Mr. H. W. Overman, the county surveyor, made a careful series of measurements of these directions. "Of twenty-four observations, fourteen were found south 53° east. Four points showed south 65° east; one south 46° east; one south 57° east. The points that showed south 65° east overlie the other exposures, and probably indicate a real change of direction in the wave action."

THE NATURE OF THE RIPPLES AND THE PERSISTENCY OF THE RIPPLE DIRECTION

These observations which are given above in full suggested to the writer that further similar observations over a wider area might prove of value in the interpretation of the geography of the Bedford-Berea sea. Accordingly determinations of the direction of the ripple-marks in both the Bedford and Berea have been made sufficient practically to cover the whole of the outcrop in Scioto and Pike counties and most of Ross County, an area about 50 miles in length (from north to south) by 20 in breadth. Observations at three localities in central Ohio, Lithopolis, Gahanna (Rocky Fork), and Sunbury (Rattlesnake Creek), show that the same persistency continues to the northward, *a total distance from the Ohio River of 115 miles.*

The results of 149 observations have been merely to confirm Orton's observation on the original much smaller area, as to the general direction of the ripples. However, his statements as to the extreme persistency of the 53° angle are not borne out, and, if the area as a whole is considered, no tendency is apparent on the part of the higher surfaces to carry ripples trending more nearly east and west, as he seems to have found them.

At all points where several rippled surfaces are exposed, variation in direction is found, and not infrequently where one surface is exposed continuously for some distance, considerable change may be found in the direction of the ripples which cover it. This, of course, is to be expected. Not infrequently a range of five or ten degrees will be found on an outcrop showing possibly only six or eight surfaces; indeed, as great a range can be found in one ripple

[1] *Geol. Surv. Ohio*, Vol. II, Part 1 (1874), 620.

within a few feet along its length. Just below Denver in Pike County, two widely variant sets of ripples were observed on adjacent planes less than an inch apart, one trending N. 28°[1] W., the other N. 55° W. Such an extreme difference is unusual, but differences of six or eight degrees between adjacent planes can be found without effort. The greatest range noted at any locality is 43°, in the Berea grit below Denver in Pike County. The widest extremes found in the area from Chillicothe southward are N. 22° W., and N. 78° W., a range of 56°. The latter has been recorded several times, especially in the southern part of the area, but the former is an unusual direction. It was found on one plane in the Berea north of Clifford, Scioto County, associated with a number on which N. 60° W. was markedly dominant. In the central Ohio outcrops the extremes are N. 9° W. (on three superimposed planes at Sunbury) and N. 78° W. at Gahanna. This is the absolute range for the whole region, 69°.

Most of the ripple directions noted in the course of the present work have been drawn in on the accompanying map. (Fig. 3.) At some points where a number of directions have been noted, not all are plotted, but in every case where more than one direction has been found, the extremes have been drawn in. On the other hand, at many localities where the ripples persistently trend in one direction, only one observation is plotted, and at almost all points where considerable variation is indicated some one direction lying between the extremes is certain to be dominant, although not so indicated. Thus the map is really a map showing *extremes* of ripple direction, not only areally but vertically. If the directions were drawn in, in the order of their persistency, the amount of variation which exists would largely be obscured, and the unity of the direction would be much more impressively set forth. As it stands, however, it is sufficient to indicate clearly that some factor must have controlled the ripple direction in central and southern Ohio during the time when the upper part of the Bedford and Berea were accumulating.

The ripples are entirely (so far as observed) of the oscillation

[1] Observations are all compass readings. The magnetic declination is one degree or less west of the true north (determined in 1906).

type, that is, formed by the slight forward-and-back motion of the water which is caused by the passage of a wave. Not a single occurrence has been noticed which suggests typical "ripple-drift," the type of ripple which is produced by strong currents of water moving in one direction. The ripple crests are usually from three to five inches apart and rarely reach six inches. This interval varies within a few feet on any surface.

Considerable experimental work has been done on the ripple-marks produced in sand by such waves. Notable is the work by Forel,[1] A. R. Hunt,[2] and G. H. Darwin.[3] The work of these men shows that, when a wave passes over a body of water, the slight oscillation of the water beneath it can be detected to a considerable depth below the surface. To what limit it may extend is unknown. This oscillation sets up small vortices in the water next the bottom, and in the course of time sand ripples are produced by the action of these vortices. These sand ripples are produced at right angles or nearly at right angles to the direction of movement of the wave: that is, they are approximately parallel in direction to the lateral extent of the wave. If the waves on a body of water extend in a northwest-southeast direction (at right angles to the direction of their movement) the ripples generated by them in the sands of the bottom would trend, in general, in the same direction. If we are seeking the factor which controlled the sand ripple directions in the Waverly, we find it directly in the waves which have produced them. It then remains to ask how the direction of water-waves is controlled, and what kept them practically parallel over a wide area throughout a considerable interval of geological time.

Hunt[4] has recorded his observations on ripple direction on the north shore of Torbay which faces the English channel toward the southeast. A portion of the beach examined was so protected

[1] "Les rides de fond," *Archives des Sciences Physiques et Naturelles Genève* (1863). This paper has not been seen by the writer but his results are stated, apparently quite fully, in the paper by Darwin.

[2] "On the Formation of Ripple-Marks," *Proc. Royal Soc. London*, XXXIV (1882), 1–18.

[3] "On the Formation of Ripple-Mark in Sand," *Proc. Royal Soc. London*, XXXVI (1883), 18–43.

[4] *Ibid.*, 6 and 7.

by a breakwater as to receive waves from the southwest only, while farther west along the shore, as the influence of the breakwater became less and less, the waves came from the south and then from the southeast. The beach was examined after a week of calm weather on the day following one on which there had been a slight swell. The sand ripples were found to correspond closely to the direction from which the waves came. Behind the breakwater their trend was northwest-southeast, parallel to the waves coming from the southwest, but as the control of the barrier became less and less to the westward, the ripple directions changed to east and west and then to northeast-southwest, as the waves came from the south, and then from the southeast.

These observations show the independence by wave direction from wind control, the control of wave direction by shore line, and the dependence of ripple direction directly on wave direction.

The parallelism of waves to coasts is generally known, and examples could be multiplied from the beaches of the eastern United States and elsewhere. Since, however, there is no data as to the direction of the ripples induced by these waves, no other need be added here.

In discussing the parallelism of the Bedford-Berea ripples with various persons, it has been suggested that it might indicate the direction of the prevailing wind. In the present geological period the direction of the prevailing winds in Ohio is from the westward. But the actual winds experienced, as a result of the cyclonic control of weather, are so variable that it is impossible to assume that the persistency of the Bedford-Berea ripples could be maintained under similar conditions of cyclonic variation, if those ripples were controlled *directly* by the winds. If they are held to indicate wind direction, we must postulate a series of winds in Bedford-Berea time more uniform in direction, even, than the trade winds, which not infrequently may vary throughout the whole range of the compass in the course of a year, as shown by almost any sailing chart of those regions, and always vary through more than a quadrant of the compass.

On the other hand, granted that the winds initiate the water waves, as soon as they come within the influence of shallow water

they are retarded more in the shallower portions, so that by a process of wave-refraction they are soon brought into a line roughly parallel with the contour lines of the bottom. And the contour lines of the bottom, on all gently sloping coasts, are nearly parallel to the shore line.

The conclusion seems to be warranted that the persistency of direction of the ripples of the Bedford and Berea indicates the prevailing direction of the water waves which formed them, and that this in turn was controlled, either by a shore line or water so shallow as to bring the waves into adjustment parallel to this shore line, or, if it was only shallow water control, to the contours on the sea floor. The shales of the Bedford clearly indicate that there must have been an open sea to the northeastward. Toward the southward the sediments become more sandy and on the whole coarser (the sandstone becomes but slightly coarser but increases very much in relative amount). From this we conclude that either a shore line or shoal water lay toward the southward with decreasing depths of water in that direction sufficient to cause wave refraction. This shore line or the contour of the bottom must have been parallel to the ripple direction, that is, it must have extended in a northwest-southeast direction.

Probably the sea in which these sediments accumulated was of moderate depth, sufficiently so that sedimentation would be continuous. The only evidence of occasional currents which were strong enough to erode locally is found in the middle and upper part of the Berea in central Ohio where the ripples are much less numerous. Quite probably it may have been sufficiently shallow and so well inclosed and protected that currents and waves of oceanic proportions could not develop.

CHANGE IN RIPPLE DIRECTION IN PASSING FROM NORTH TO SOUTH

A brief survey of the map suggests that the directions along the Ohio River tend more nearly east and west than they do farther north. The number of directions occurring within each five degrees has been plotted in four areas. This brings out the fact that there actually is a swing in the direction of the majority of the ripples to more nearly east and west in southern Ohio. In

central Ohio the greatest number trend between N. 50° and 55° W. In Pike and Ross counties by far the greatest number trend from N. 55° to 60° W. In northern Scioto County the maximum is between N. 60° and 65° W., and along the Ohio River it falls between N. 65° and 70° W. The significance of this definite and controlled variation is not apparent at present. The occurrence is merely noted in passing as suggesting one of the methods of attack in such a problem which may yield results.

EVIDENCE FROM THE RIPPLE DIRECTION ON THE ATTITUDE OF THE CINCINNATI AXIS AT THIS TIME

The region of the Cincinnati uplift lies but a few miles to the westward of the area in which the ripples are mapped. This is known to have been a region which from the end of the Ordovician onward tended to maintain a somewhat elevated attitude. According to Schuchert[1] it is one of the positive elements of the continent. That is, it tended to be an island or a region of shallow water while sedimentation was going on in adjacent territories. The axis of the Cincinnati uplift trends nearly north and south, slightly northeast-southwest. With its continuation, the Nashville uplift, the axial trend of the whole is decidedly more northeasterly.

In seeking a coast line which controlled the ripple direction, this positive element suggests itself at once. It has been generally held that there was land in that quarter throughout the Mississippian period and such is indicated on Schuchert's map of this stage.[2] However, by comparing the ripple directions with the present axis of the uplift, as indicated on the outline map of Ohio (Fig. 2), it can readily be observed that the ripples stand almost at a right angle to the axis. If it is supposed that the Cincinnati dome stood high at that time with its axis as at present, it is necessary to assume that within a few miles, certainly not more than 30, to the westward, the ripples were sharply bent into parallelism with this axis. The fact that the ripple direction shows no tendency whatever (the observations are sufficient on this point) to swing into such adjustment to the westward is held to be sufficient

[1] *Bull. Geol. Soc. Am.*, XX (1910), 470.

[2] *Ibid.*, Pls. 78, 79.

evidence that there was no such control in that direction at that time.

Futhermore, the axis which lay to the southward and which did control the ripple directions was directly transverse to the present Cincinnati axis. Whether or not this axis is to be considered as the result of the same forces and conditions which determined the Cincinnati axis, but which were operating in a different manner during Bedford-Berea time, is a question whose answer is, perhaps wholly, a matter of personal opinion. The question is one of some importance in determining the nature of forces and conditions lying back of such a positive element of the continent. The case is of especial interest in view of the fact that, in the Cuyahoga formation which almost directly succeeds the Berea,[1] there is positive evidence of a different nature that the Cincinnati dome had nearly the axial alignment which it holds at present for at least 40 miles north of the Ohio River where the evidence is lost, due to the swinging of the outcrops to the eastward.

In view of the suggestion that the shore line lay to the southward, a word is desirable as to the nature of the Bedford and Berea formations in that direction. W. C. Morse and A. F. Foerste have traced them southwestward into Kentucky for 80 miles and show that the horizon thins rapidly, being reduced at some points to two or three inches.[2] The sandstones and ripple-marks (directions not noted) are still in evidence 18 miles south of the Ohio River where the horizon is only 46 feet thick (as against over 100 in Ohio). Beyond this it is much reduced, and consists almost wholly of argillaceous or calcareous shale, presumably very like the basal Bedford in Ohio.

The authors mention the possibility that only the basal part of the Bedford may be represented in this southern extension, but reject the idea, holding that, even when reduced to two inches, the horizon is "Bedford-Berea." To the writer, who knows the area only from their paper, there seem to be many facts which strongly favor the removal of the Berea and much of the Bedford

[1] The Sunbury black shale, 10 to 20 feet thick, intervenes.

[2] "The Waverly Formations of East Central Kentucky," *Journal of Geology*, XVII, 164–77.

by erosion, prior to the formation of the next succeeding Sunbury shale, and their suggestion cannot lightly be laid aside. These facts are: (1) the presence of a fauna which is found only in the lowermost two or three feet of the Bedford at Gahanna (Franklin County), Bainbridge (Ross County), and Piketon (Pike County), the only localities in central and southern Ohio where the contact has been observed. In Kentucky a portion of the same fauna is found when only a fraction of a foot is present. (2) At one point, Olympian Springs, Bath County, Morse and Foerste note the following variation in thickness of the "Bedford-Berea," within two and one-half miles: $12\frac{1}{2}$ feet, $5\frac{3}{4}$ feet, 2 inches. This is an extreme case but irregularity in thickness is the rule in the sections they present. (3) The absence of beds corresponding to the Berea as soon as the thickness is reduced to less than 70 feet. (It is not apparent that the $7\frac{1}{2}$-foot bed they refer to the Berea in the Elk Lick section, where the total is reduced to 70 feet, is really Berea and not a horizon in the Bedford. Many such occur in the Bedford to the northward.)

It is thus uncertain, and perhaps unknowable except by inference, what the true conditions in Bedford and Berea time were to the southwestward. If, as seems probable to the writer, only the basal beds are present, they are not indicative, for the basal beds throughout southern Ohio are largely shale.

It seems probable that the northwest-southeast axis in Kentucky, which was prominent enough during late Bedford and Berea time to control the ripple directions, was elevated at the close of that period so far as to permit the removal of almost the whole of these deposits. Possibly this uplift did not succeed the formation of the Berea of southern Ohio, but was contemporaneous with it, and the extension of the Berea (so called) over southern Ohio was due to the northward translation of the shallower water deposits resultant on the uplift. No evidence has been brought forward bearing directly on this point.

SUMMARY

The Berea of central and southern Ohio is largely a phase of the Bedford but is readily distinguished by the much greater amount

of sandstone present. Ripple-marks are abundant in the sandstones of the upper half of the Bedford and most of the Berea. From the Ohio River to the center of the state, a distance of 115 miles and over a width of 20 miles, these ripples are remarkably persistent in direction, trending northwest-southeast. In central Ohio the great majority range between N. 40° and N. 55° W. In passing southward the direction swings gradually to more nearly east and west, the majority on the Ohio River ranging from N. 60° to 70° W. The absolute range of observations for the whole region is only 69°. The cause of the progressive variation from north to south is not apparent.

The general persistency of direction is believed to be due to parallelism to the shore line of that time, which lay to the southward, and the direction of the ripples is believed to indicate the approximate trend of this shore line. If such is the case, it is probable that the Cincinnati axis of that time was not appreciable as an uplift, or, if active, maintained an attitude quite different from that holding at present.

The evidence indicates the presence of shoal water, or possibly a land body, to the south-southwestward the axis of which was almost normal to the present axis of the Cincinnati uplift. From the work of Morse and Foerste it seems probable that this axis became more active later, perhaps closing the Bedford sedimentations with uplift and erosion. The Berea of southern Ohio may be the result of the northward pushing of the strand line by this uplift.

A POSSIBLE LIMITING EFFECT OF GROUND-WATER UPON EOLIAN EROSION

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Mr. C. R. Keyes, in a recent article in the *Journal of Geology*,[1] discusses the well-known fact that in arid regions erosion proceeds independently of sea-level and often is effective even below it. He sets a limit, however, to the depth to which eolian erosion can extend, in these terms: "Where the general ground-water level nearly coincides with that of the plains-surface, deflation can proceed no farther. This level, which is perfectly independent of sea-level, can never be very far below it." In this connection, it may be of interest to call attention to some suggestions regarding the effect which ground-water, existing under a special condition, may have upon erosion.

Mr. H. J. L. Beadnell,[2] in 1909, describes the Kharga Oasis, which is a depression in the Lybian Plateau of Egypt, worn down beneath the general level of the country by the differential effect of subaerial denudation acting on rock masses of varying hardness and composition. He states that the oasis was at one time the bed of an extensive lake, and, from the finding of some fragments of pottery *in situ* in the base of the lacustrine deposits, concludes that the lake was contemporaneous with man. In regard to its origin, he says:

> There is an explanation which it is advisable to keep in mind, though it has never hitherto, as far as I am aware, been advanced as a possible cause of the formation of lakes. . . . . There is little doubt that the beds which we have named the "Surface-Water Sandstone," and which are now exposed in places on the floor of the oasis, were originally entirely covered by impervious clays and contained artesian water under pressure. It is conceivable, therefore, that when

[1] "Base Level of Eolian Erosion," *Jour. Geol.*, XVII (1909), 659–63.

[2] *An Egyptian Oasis: An Account of the Oasis of Kharga.* London, 1909; abstract, *Geol. Mag.*, VI (1909), 476–78.

those beds became exposed at the surface, owing to the removal of the overlying confining strata, their contained water escaped in such quantities as to have given rise to a lake of considerable dimensions.

A lake formed in such a manner would certainly put a sudden stop to the downwearing effects of deflation.

Mr. H. G. Lyons,[1] on the other hand, in an article written many years before, states that during the erosion of the Nile Valley the cutting-back of the escarpment separating the overlying limestones from the underlying Nubian sandstone encroached upon the southern limit of the oases, and let loose springs which greatly increased the rate of erosion. This would appear to be a case where the presence of ground-water facilitated erosion.

Again, Mr. F. J. Bennett,[2] in 1908, seems to have the germ of the same idea, when, discussing the solution-subsidence valleys and swallow holes within the Hythe Beds area of West Malling and Maidstone, England, he suggests that the "upward hydrostatic action of water under pressure . . . . is a new contributing factor in valley formation, and that this in conjunction with subaerial stream erosion" formed the valleys and swallow holes described. This, however, is an application to a region of normal rainfall and is not strictly à propos.

The idea advanced by Mr. Beadnell may be applicable to other desert regions. It is, at any rate, worth considering, in connection with Mr. Keyes's article, as a possible *modus operandi* of one limiting effect of ground-water upon wind erosion.

[1] "On the Stratigraphy and Physiography of the Lybian Desert of Egypt," *Quart. Jour. Geol. Soc.*, L (1894), 531–47.

[2] "Formation of Valleys in Porous Strata," *Geog. Jour.*, XXXII (1908), 277–88.

RECENTLY DISCOVERED HOT SPRINGS IN ARKANSAS

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Though the hot springs at the city of Hot Springs, Garland County, Arkansas, probably have been known since the time of De Soto, the existence of other thermal springs within the state was not even surmised until February, 1908. At that time, a man named J. M. Davis, who was then living in or near the town

FIG. 1.—Caddo Gap, from the south

of Caddo Gap, Montgomery County, discovered other thermal springs issuing from the bed of Caddo Creek in the gap where this stream cuts through Caddo Mountain. This gap is 31 miles west, and 10 miles south of Hot Springs.

As the region about the gap is densely settled, as there has for many years been a small town within a half mile of it, as it is traversed by a wagon road, and as the stream at usual stage is

easily forded where the springs issue, it seems remarkable that they did not attract the attention of someone long ago.

Caddo Mountain is one of the numerous east-west ridges that constitute the Ouachita Mountains of west-central Arkansas. Its height in the vicinity of the gap is 1,250 feet above sea-level, and 600 feet above the stream level. As with all the other ridges of the area, the rocks of this one have been disturbed by folding, and, in addition to the folding, they have been faulted at the gap; and like most of the other ridges, including the one from which the springs of Hot Springs issue, the rocks are of the siliceous type known as novaculite.

At Caddo Gap, the rocks are on edge, and strike north 80 degrees east, across the stream. They are here intersected by a thrust fault, as shown in Fig. 2, with an east-west strike.

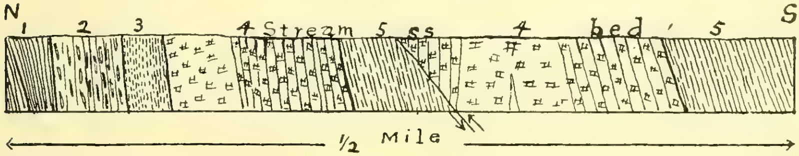

FIG. 2.—Showing the geological section and the rock structure at Caddo Gap. Also, the location of the thermal springs. 5, Stanley shale (Carboniferous); 4. Arkansas novaculite (age undetermined); 3, Missouri Mountain slate (age undetermined); 2, Bigfork chert (Ordovician); 1, Polk Creek shale (Ordovician); *ss*, Thermal springs.

Two springs are known, and their waters rise between the vertical beds of novaculite. Possibly there are others that have not yet been detected. At the time of discovery, all the water of the springs issued below the stream level, but the points of emergence have in part been closed with cement, so that some of the water now issues from the west bank of the creek. For convenience, the springs are here spoken of as the north and the south spring. The surface of the north spring stands about 15 inches and that of the south spring about 10 inches above the surface of the creek at average stage.

The north spring is about 40 feet south of the fault, and the south one 25 feet farther. The temperatures of the two springs, on July 2, 1910, as determined with a physician's thermometer,

were 95 degrees and 96.5 degrees respectively. Doubtless the temperature is much reduced by the water of the creek and if so it varies with the seasons. The rock layers between which the water issues are quite warm to the touch beneath the surface of the stream. From a rough determination, the flow of each spring was calculated as 5 gallons per minute. A small bathhouse has been improvised, into which water from the south spring is pumped by hand.

A sample of the water from each spring was taken by the writer and sent to Dr. W. M. Bruce, chemist of the Arkansas Experiment Station at Fayetteville, for analyses. These analyses and the average analysis of seven of the springs at Hot Springs are recalculated and the results given in the following table:

	Caddo Gap Thermal Springs		Average of Seven Springs at Hot Springs
	South Spring	North Spring	
Constituents	Parts per 100,000*	Parts per 100,000*	Parts per 100,000†
SiO_2	1.5600	1.8700	4.4450
$Fe_2O_3+Al_2O_3$	0.7000	0.7200	......
K	0.0000	0.0000	0.1934
Na	0.7526	0.3349	0.4421
Ca	3.8876	4.1680	4.9370
Mg	0.2166	0.4235	0.5621
Fe	......	......	0.0317
Cl	0.4848	0.7138	0.2819
CO_3	6.8265	6.7085	8.8034
SO_4	0.1419	0.2313	0.7689
Total	14.5700	15.1700	20.4655
Free CO_2	2.0000	1.6000	......
Grains per U.S. gallon	8.44	8.79	11.88

* Recalculated from analyses by Dr. W. M. Bruce, who gives the constituents as if in (hypothetical) combination; except SiO_2 and $Al_2O_3+Fe_2O_3$. In the recalculation, results were carried out to the fourth place of decimals in order properly to distribute the constituents.

† Recalculated from data given in *Ann. Rep., Geol. Surv. of Ark.* (1891), I, 19, where constituents are hypothetically combined, and are stated in grains per U.S. gallon.

The similarity of the analyses is striking, but this would be expected in water flowing through the same formations, as these do. It will be noticed, however, that the water of the springs at Caddo Gap somewhat excels in purity the springs at Hot Springs, which are themselves very pure.

To the geologist, of course, the interesting thing in connection

with these springs, as with the longer-known ones at Hot Springs, is the possible source of the heat. Is this due to (1) chemical reactions within the rocks through which the water flows, or (2) accumulated heat from friction, or (3) the presence of hot igneous rocks beneath the surface, or (4) the breaking down or other action of radium along the underground course of the water?

The unusual purity of the water seems conclusive evidence against the first hypothesis. Granted that heat from friction can be so accumulated as to bring the rocks to a high temperature, there is no evidence of recent crustal movement within the region where the springs occur. The location of the springs is doubtless due in large measure to the fault, but this probably was formed at the time of the folding, and if there ever was any localized heat accompanying the crustal movements, it would be expected to have been dispersed long ago. Dr. J. C. Branner, many years ago, stated that the temperature of the waters at Hot Springs is probably due to their coming in contact with masses of hot rocks.[1] In support of this, there are outcropping igneous dykes in and near the city of Hot Springs, and igneous areas of some extent only a few miles distant. While there are no known igneous rocks in the immediate vicinity of Caddo Gap, there are small outcrops in the vicinity of Crystal Springs 18 miles to the northeast, and a small igneous area near the town of Murfreesboro, 22 miles to the south. All these igneous outcrops are of Cretaceous or post-Cretaceous age. So it seems not out of the possibilities that the temperature of the water at Caddo Gap is due to its flowing over hot igneous rocks. Whether or not the radium hypothesis has any value probably could be determined by testing the water for unusual radio-activity. This has not been done.

[1] *Ann. Rep., Geol. Surv. of Ark.* (1891), I, 10.

Reviews

The Ore Deposits of New Mexico. By Waldemar Lindgren, Louis C. Graton, and Charles H. Gordon. Professional Paper 68, U.S. Geological Survey, 1910. Pp. 361.

This paper treats a subject about which most geologists have known comparatively little, and of which most of us are eager to learn. Although some of the mining districts were worked by the Spaniards long before the United States became a mining nation, the geology and ore deposits of the state are less well known, perhaps, than those of any other portion of the country. During the past decade several papers treating the deposits of large areas have appeared, and these, the reviewer believes, have contributed fully as much to the science of economic geology as the more intensive studies of small areas. The reconnaissance method of study and treatment gives a perspective which detailed work of small and more or less isolated mining districts could never do. This paper is the most comprehensive and in its scientific aspects should be the most useful of its class. The deposits are so varied and their genesis so clearly discussed that the student of ore deposits will find the paper to possess the essentials of a textbook of mining geology.

Pre-Cambrian rocks do not occupy large areas in New Mexico; the largest masses are found in the north and constitute the southern extension of the Sangre de Cristo Range of Colorado. This belt ends some 20 miles south of Santa Fé. Several other, smaller areas of pre-Cambrian rocks are described. The pre-Cambrian rocks consist of quartzites, mica schists of clastic origin, and some limestones. These are intruded by normal granite, which in turn has been intruded by masses and dikes of dioritic rocks. The latter are at some places cut by pegmatite dikes and by a later granite. Schistosity in varying degrees has been produced in both the sedimentary and the igneous rocks. At some places the granite breaks through or contains remnants of older greenstone tuffs, amphiboles, and rhyolites. The pre-Cambrian sedimentaries probably correspond in age to those imbedded in red granite in various places in Colorado. Perhaps they should be correlated also with the quartzitic Pinal schists of southeastern Arizona.

The pre-Cambrian history, one of sedimentation, mountain building, and igneous intrusion, was followed by long-continued erosion,

which exposed the ancient cores. At the base of the Paleozoic is pronounced unconformity. During Cambrian times a land mass probably occupied the northern portion of the state. South of this, fossiliferous Cambrian beds rest upon the ancient complex. The sea shore moved northward during the Paleozoic, and the Ordovician, Silurian, and Carboniferous beds overlap the Cambrian, and extend farther north. In the northern part of the state the Upper Carboniferous rests directly upon the pre-Cambrian, and these conditions continue as far south as Socorro. The Cambrian consists of quartzite, shales, and limestones; the Ordovician is predominantly of limestone; the Silurian of limestone and quartzite.

The fossiliferous Devonian, represented in the western part of the state, is a thin formation of clay shale, calcareous in the upper portion. At some places it is believed there is an unconformity of erosion between the Ordovician limestone and the Devonian, but at many places they are conformable.

The Mississippian is recognized at several places south of latitude 34°. The Pennsylvanian is deposited with considerable thickness over the whole state, reaching a maximum between Santa Fé and Las Vegas. As far south as Socorro, it consists of sandstone and shales in repeated alternation with limestone beds. Farther south the pure limestone prevails and the total thickness appears to diminish. All indicates near shore conditions in the northern part of the state. The upper Carboniferous is divisible into two groups, the upper one of which is of the Carboniferous "Red Beds." Unconformities of erosion mark both the top and bottom of the group. Triassic "Red Beds" are unknown in the southern part of the state, but have been described in the Sierra Nacimiento.

The Cretaceous rests upon the eroded "Red Beds," the Carboniferous, and the pre-Cambrian. This series consists of pliable shales which once extended over the whole territory with greater continuity than any other formation except perhaps the Early Pennsylvanian.

The Tertiary was marked by igneous activity, mountain making and ore deposition. First, manganitic magmas were thrust out as laccolithic masses beneath the pliable, tough Cretaceous sediments. Marine conditions ceased. Lake basins developed, at least in northern New Mexico. Mountain building accompanied and succeeded intrusion. These forces were active mainly in the belt extending southwestward—the extension of the Rocky Mountain region. The pre-Cambrian core to the north was forced up by faulting or by warping and faulting.

Southward the sediments were broken into faulted monoclines—the typical Great Basin structure. Erosion was active in shaping the mountain ranges, especially in the southwest. A second epoch of igneous activity, distinctly separate from the earlier epochs of intrusion, began, probably in Middle Tertiary, as in Nevada, Colorado, Utah, and in general throughout the central West, and andesites and rhyolites, in places 2,000 feet thick, were extravasated upon beveled sedimentaries. A large Miocene lake covered the upper Rio Grande Valley, in part at least. In this, the Santa Fé marl was deposited. Near the close of the Tertiary, basalts covered this marl, and the eroded older sediments and igneous rocks.

These eruptions continued during Quaternary times. In early Quaternary, land deposits of coarse gravels filled some of the structural troughs to a depth of 1,000 feet. Basalt was poured over these gravels and smaller flows, perhaps only a few hundred years ago, were extravasated at several places.

The highly acidic potash-rich granites, products of the pre-Cambrian igneous period, differ greatly from the Tertiary monzonites, quartz monzonites and their lava equivalents, and it is concluded that these two series could not have been derived from a common magma. It is suggested, however, that the Tertiary rocks were derived from the same source and that toward the last a differentiation took place in a magma basin the products of which were basalts and rhyolites.

The mines of the state, it is estimated, have produced some 35,000,000 ounces silver, and $30,000,000 gold, besides considerable lead, copper, and zinc. Like the area of maximum of orogenic activity, fissuring and igneous intrusion, the deposits extend southwestward, through the state, forming a broad belt about 450 miles long, in which eighty-one mining districts or camps are located. Many types of deposits are represented, among them copper and iron ores in sedimentary beds, fissure veins, mineralized shear zones, lenticular veins in gneiss, replacement veins in limestone, irregular replacement deposits in limestone, contact metamorphic deposits and gold placers. At least three epochs of mineralization are represented: (1) Pre-Cambrian, (2) Early Tertiary, (3) Middle and Late Tertiary. There are also, in the "Red Beds" (Carboniferous and later), deposits which are not related to igneous activities and which were formed presumably by cold solutions, in post-Carboniferous times.

The pre-Cambrian deposits are represented in ten districts. Three types have been recognized, quartz-filled fissures, usually of the lenticu-

lar type; shear zones filled with quartz stringers; disseminations of sulphides in amphibole schists. They are in greenstone, granite, gneiss, or amphibolite. Some of these deposits are accompanied by sericitization and the development of horny silicates in the wall rock. Some have been subjected to the stresses of dynamic metamorphism and show the effect of pressure in lenticular development of quartz and in the development of minerals like biotite. The values are gold, silver, and copper. Minerals represented in these deposits are quartz, calcite, siderite, flourite, tourmaline, biotite, epidote, garnet, chlorite, specularite, pyrite, pyrrhotite, chalcopyrite, galena, zinc blend, molybdenite, tetrahedrite, bornite, and chalcocite. It is suggested that these ores are genetically related to the granite magma. The pre-Cambrian deposits are not extensively developed.

Contact metamorphic deposits are developed where the early Tertiary intrusives, consisting of monzonites, quartz monzonite, granodiorites or their porphyries, cut through limestone or calcareous shale. Metamorphism is not excessive and rarely extends more than a few hundred feet in a horizontal distance. Mineralization usually accompanies metamorphism. Copper, as chalcopyrite, is most common in the contact metamorphic deposits, but is usually accompanied by zinc blend. Magnetite is locally developed. With two exceptions, gold and silver are present as traces only. Galena is generally subordinate; pyrrhotite is not common. Other minerals are quartz, calcite, garnet, epidote, wollastonite, tremolite, specularite, magnetite, pyrite, molybdenite. Some of these deposits are important. Indicating a transition between contact metamorphic deposits and fissure veins formed by magmatic solutions under conditions of less temperature and pressure, there are fissure veins in limestone, the walls of which are in part converted to garnet and other heavy silicates. The magmatic solutions causing contact metamorphism added silica and the metals to the rocks intruded.

Certain veins, not replacements in limestone, are in close genetic relation to the same early Tertiary intermediate porphyries, which locally produced contact metamorphic mineralization. Perhaps $20,000,000 gold has been derived from these veins, which are believed to be of deep-seated origin. In a few of these veins silver is the most important metal. Quartz, pyrite, and gold are almost always present; barite is exceptional. Tourmaline, specularite, pyrrhotite, magnetite, flourite, molybdenite, have been noted. Other minerals are calcite, dolomite, chalcopyrite, galena, zinc blend. Wall-rock alterations are

sericitization, carbonatization, silicification, and pyritization; hydrothermal alterations are less extensive than near the vein deposits of the Middle Tertiary age. At Sylvanite, orthoclase (not adularia) is found in small veins more or less closely related to pegmatites, but which are notwithstanding far from the normal pegmatite.

The Santa Rita (Chino) and Burro Mountain deposits also were probably formed in the first concentration at the time of the intrusion of the early Tertiary porphyries. These disseminated copper ores are greatly concentrated by oxidizing surface waters and resemble in many respects the "copper porphyries" of Arizona, Utah, and Nevada.

Replacement deposits in limestone, not contact metamorphic deposits, form an important group which is likewise in close genetic relation to the early Tertiary intrusions. At Lake Valley the eroded ore deposits are covered by andesite. Strongly indicating deposition by ascending magmatic solutions, these deposits have been found in eight of the districts below beds of shale. In six other districts they are fissure veins. Silver is generally the most important metal; lead is almost always present; gold is absent, barite is rare.

The gangue is siliceous, with one or more carbonates. Other minerals are fluorite, wulfenite, vanadite, zinc blend, pyrite, chalcopyrite, argentite, cerargyrite, silver, limonite, and pyrolusite. No heavy silicates are found in the limestone along these veins, but silica or jasperoid has been developed.

Veins of gold and silver ores connected with volcanic rocks of Middle Tertiary or later age are developed in ten mining districts. They are contained in rhyolites, its tuffs and breccias, or in andesites, which have latitic transitions. Some of these deposits are older than early Quaternary basalts. Base metals and sulphides are not prominent in these veins, lead and zinc are rare, though copper is present in considerable amounts in several districts. The gangue is quartz, which may be accompanied by calcite, fluorite, and barite. Adularia is present in two districts. Pyrite and chalcopyrite are common; bornite is probably primary. Other minerals are zinc blend, galena, chalcocite, telluride, tetrahedrite, cerargyrite, etc. Hydrothermal alteration is widespread. These veins are believed to have been deposited by hot waters very near the present surface at the time of deposition. Possibly the waters, such as those which have been analyzed from hot springs at Ojo Caliente, are solutions of the same genesis and character. The discussion of the relation of the deposits to waters of this character is an exceedingly suggestive and valuable section of the paper.

There are certain lead and copper veins of doubtful affiliation which do not appear to belong to any of the groups described and which seem to have no genetic relation to igneous rocks. They are, so far as developed, of small importance.

The copper deposits in sandstone, which, in part at least, replace carbonaceous material and which appear to have no direct connection with igneous rocks, form a relatively unimportant, but an exceedingly interesting group. These ores are mainly in the "Red Beds." The minerals are chalcocite, bornite, chalcopyrite, pyrite, malachite, azurite, silica, barite, and gypsum. Frequently these deposits replace coal. Some ores carry a few ounces of silver to the ton of chalcocite.

It is believed that the metals known to have been present in pre-Cambrian areas were leached out of these as sulphates, and redeposited in sediments that collected in inland lakes or seas. In part they were deposited as the solid detrital sulphides. When surface waters leached such beds, copper was dissolved. The waters of the Red Beds are known to be rich in chlorides and sulphates. From the organic matter in the beds, hydrogen sulphide would be added, and this would readily precipitate copper sulphide.

Pages 82 to 348 contain detailed descriptions of the many mining districts.

W. H. E.

Syllabus of a Course of Lectures on Economic Geology. By JOHN C. BRANNER. Published by Stanford University. 3d ed., 1911. Pp. 503.

This syllabus is intended for the use of students in college and afterward. The method of treatment of the various subjects is mainly by outlines, which are to be expanded by notes from lectures, readings, and observation, and written out on blank pages opposite the outlines. Numerous text figures and cross-sections of mines add greatly to the value of the book. The references are full, well chosen, and up to date.

W. H. E.

Descriptive Mineralogy, with Especial Reference to the Occurrences and Uses of Minerals. By EDWARD HENRY KRAUS. Ann Arbor, Mich.: George Wahr, 1910.

The book contains 334 pages of text and about the same number of blank pages for students' notes. It is designed primarily for the student of general mineralogy, with little reference to microscopical optics.

The systematic treatment of crystallography which the author published several years ago is not incorporated in the *Mineralogy*. The treatment and the lists of occurrences appear to be comprehensive. As in most textbooks in mineralogy, the references to sources of information relating to occurrences are inadequate. Such references, although adding greatly to its bulk, would vastly increase the usefulness of a textbook on mineralogy. A valuable feature is a group of tables listing separately the minerals containing each element.

W. H. E.

The Pleistocene Deposits in Warren County, Iowa. By John Littlefield Tilton. Chicago: The University of Chicago Press, 1911. Pp. 42; figs. 7.

As Warren County lies just south of Des Moines beyond the reach of the later ice invasions, the chief Pleistocene features of this region are the sub-Aftonian and Kansan till sheets, the interglacial Aftonian sands and gravels, and the post-Kansan loessial and other deposits. The most serious problem is found in differentiating the sub-Aftonian and Kansan tills, especially since the intervening Aftonian horizon-marker sometimes becomes so scant or obscure as to afford little help in separating the two tills. Though both till sheets were deposited by glaciers from the Keewatin gathering-ground, certain minor differences are cited by the author as distinguishing them. Large pebbles and bowlders are said to be more common in the Kansan than in the sub-Aftonian in the region under study. Among the stony constituents the author notes red quartzite as characteristic of the Kansan but not of the Aftonian and sub-Aftonian, a view supported by a series of pebble classifications made in the typical Aftonian region by the reviewer.

The author assigns much greater thickness to the sub-Aftonian than to the Kansan in the region under study and attributes much of the present topography to drainage lines cut in this older drift during the Aftonian interglacial period, believing that, while the later Kansan invasion has partially masked this Aftonian topography by concealing some of the minor valleys, it has not obliterated the larger ones.

R. T. C.

Petrological Abstracts and Reviews

Edited by ALBERT JOHANNSEN

Koenigsberger, Joh. *Erläuterungen zur geologischen und mineralogischen Karte des östlichen Aaremassivs von Disentis bis zum Spannort.* Freiburg i. B. und Leipzig: Speyer & Kaerner, 1910. Pp. 63; figs. 8; colored geological map in pocket.

This work is a geological description of a small portion of the Alps, $12 \times 26\frac{1}{2}$ km. in extent, between Disentis and Spannort, and just north of St. Gotthard. It is mapped on a scale of 1 cm. to 500 m., on one of the beautiful maps of the Swiss Topographic Bureau in Berne.

The author tentatively submits the following sequence:

1. Deposition of pre-Carboniferous sediments. These were much altered by the later intrusives and are now chiefly sericite gneiss.

2. Intrusions of diorite, diorite porphyrite, diabase, and gabbro-peridotite into Silurian and Devonian rocks. The intrusives are almost entirely altered to amphibolites but the original rocks in most cases can be determined. The diorites are accompanied by differentiation zones of diorite-aplite.

3. Intrusions of gneiss, probably originally granite, into upper-Devonian rocks, and forming a low-arched laccolith. By this intrusion the former eruptives and the sediments were metamorphosed into crystalline schists.

4. Intrusions of syenite, followed by biotite and hornblende granite (Piz Ner), of middle or upper Carboniferous age.

5. Intrusion of the Aar granite at the contact and beneath the previously intruded syenite. In places fragments of the latter are inclosed in the former. Contemporaneously with the intrusion came the Carboniferous folding, seen in the Wendeljoch.

6. The Jura-Trias folding and thrust faulting of the Alps followed next and produced further metamorphism. Nowhere are there exposed in the Aar massif any contemporaneous intrusives.

The rocks are briefly described, numerous analyses are given, and the contact effects are shown. The mineral localities are described, seven excursions are outlined, and complete literature references are given.

Albert Johannsen

FARRINGTON, OLIVER CUMMINGS. *Meteorite Studies, III.* Publication No. 145, Geological Series, Vol. III, No. 8. Field Museum of Natural History, Chicago, 1910.

The publication includes: Description of a chondritic meteorite which fell near Leighton, Ala., on January 12, 1907; description of a large iron meteorite found at Quinn Canyon, Nev., in 1908; a collection of analyses of taenite; a tabulation of the well-authenticated times of fall of meteorites since 1800, compared for years, months, days, and hours of the day; and a list of the meteorites of the United States, arranged by states.

E. R. LLOYD

ROSENBUSCH, H. *Elemente der Gesteinslehre.* Third revised edition with 692 pp., 107 figures, and 2 plates. Stuttgart, 1910.

The appearance of a new edition of this standard textbook is a matter of more than ordinary interest since it represents in briefer form the results of the petrographical investigations of the last decade as summarized in the fourth edition of Rosenbusch's *Massige Gesteine.* The fact that the larger and smaller works follow the same general analysis makes the latter especially satisfactory as a textbook for advanced students who can use it.

The new edition has been thoroughly revised and, where necessary, enlarged by the incorporation of new material. The amount of such additional material is much less than might be inferred by an increase of nearly 150 pages which is due in a measure to the resetting of the work. Certain changes in classification, the firmer drawing of the systematic lines, an improvement in proportion (due to the fuller treatment of formerly neglected features), and the introduction of additional chemical data are the chief changes noted. There still remain, however, several changes which might be made to increase the logical coherence of the systematic treatment and the completeness of the chemical discussion.

The book, as in former editions, consists of three parts, dealing respectively with the eruptive (70 per cent), sedimentary (13 per cent), and metamorphic (17 per cent) rocks, preceded by an introduction.

The "introduction" remains practically unchanged except for the substitution of the new average for the composition of rocks obtained by Clarke and a brief discussion of the cone-in-cone structure.

Part I, "The Eruptive Rocks," following the earlier analysis, considers them from the viewpoint of their substance, geological occurrence,

texture, age, metamorphism, and classification. Three additions of moment are noted. These are discussions of (1) gases, based principally on the work of Gautier without reference to that of R. T. Chamberlin; (2) the relation of size of grain to the temperature in a cooling intrusive mass, based on Professor Lane's paper; (3) applicability of the phase rule to the complex hydrous and gaseous solutions of more or less dissociated material of the magma which is not an arbitrary mixture but such that when computed water free contains 184 molecules.

The systematic description of the igneous rocks divides them into three major groups—deep-seated, dike, and effusive—as formerly. The groups, in turn, are divided into 10 families, three subgroups, and 14 families respectively. Each family is described with respect to its mineral and chemical composition, texture, subdivision, geological occurrence, and distribution.

The discussion of *deep-seated rocks* shows careful revision and the incorporation of many of the results of the recent investigations. The systematic treatment is conspicuously modified by placing the discussion of the Peridotites last and by the expansion of the chapter on Ijolite and Missourite into two chapters entitled "Missourite and Fergusite" and "Ijolite and Bekinkinite." Less conspicuously there is introduced the far more fundamental conception of the division of the deep-seated rocks into three great series by the elevation of the Charnockite-Maugerite-Anorthosite series to equal rank with the better known alkali and alkali-lime series. The new series is characterized as follows:

Charnockite-Anorthosite Series.—The rock series based upon gradations in composition and association in the field passing from Granite through Syenite and Diorite to Gabbro—the lime-alkali series—and that from alkali granite through alkali syenites to Essexites, the alkali analogue of the gabbro—the alkali series—have been well recognized. There have, however, in these series been certain members lacking, e.g., the alkali analogue of the Diorite and the lime-alkali analogue of the Nephelite syenite.

Each of the series has its own areas of occurrence and the different members of a series are usually intimately related in occurrence while members of the alkali series never occur in regions of lime-alkali rocks.

We find now among the Plutonic rocks, a type whose mineral composition is of the same sort as the gabbro—the anorthorite and labrador fels—which, notwithstanding its chemical character and association, varies throughout from the gabbro. This anorthorite type we find in association with the hypersthene granite or charnockite, and here, moreover, the silica-rich charnockite is connected by a number of intermediates with the silica-poor anorthosites, so that we may speak of a charnockite-anorthosite series which even has peridotite or pyroxenic end members. . . . .

The number of occurrences of rocks of the charnockite series is, on the

whole, not as great as those of the other two series and especially the intermediate members between the charnockite and the anorthosite are as yet but little studied.

The series includes charnockite, maugerite, anorthosite, and kyschtymite, and is represented in Canada, Norway, Russia, Saxony, and the type locality of Madras described by Holland.

The analyses show with a rise in silica a decrease in anorthite and, when this is over 56 per cent, the content of the alkalies, producing microperthites, rises rapidly at the cost of the lime-soda feldspars until the granitic type of the series is reached.

The uncertain touch in handling this new series is striking evidence of the evils of combining the elements of genesis and composition in a systematic presentation of rocks. Either the integrity of the series rests upon the chemical similitude of its members or in their genetic association. It cannot rest on both as of equal supporting value. From the treatment of this new series by Rosenbusch it is impossible to credit him with a clear concept without charging him with serious defects in revision. The series is introduced incidentally (p. 182) without any forecasting of its existence in the general discussion or in that of the granites where a typical member of the new series (Hypersthene granite from Birkem) is cited as a member of the alkali-lime granites, at least by implication. Moreover, charnockite itself is described briefly (p. 94) without reference to the new series, while the index to the volume itself shows no reference to its discussion on p. 182. That it is possible to erect a new series may be seen from a study of Osann's analysis, since rhyolite, micatrachyte, dacite, amphibole-andesite, aplite, granite, and alaskite show the chemical characteristics assigned to the series, viz., relatively high alumina, lime, and the alkalis, low iron, magnesia, and varying silica.

The discussion of the Essexites, the Shonkinites, and other "basic alkali" deep-seated rocks has been entirely rewritten and expanded by embodying the results of the studies of Hibsch in Bohemia, Lacroix in Madagascar, and others in different areas.

The chemical discussion at the end of the chapter on the deep-seated rocks is enriched by the graphic representation of the analyses according to the scheme proposed by Osann and by a short tentative discussion of the molecular character of the magmas.

The discussion of the *dike rocks* is little changed from that of earlier editions. A slight modification in terminology from granite porphyry to *granito-porphyritic* is noted at the beginning but not consistently followed, and the introduction of granito-porphyritic rocks equal to the alkaline and basic alkaline rocks has been made to improve the symmetry

of the discussion. The treatment of the eleolite-porphyries has been rewritten and a section describing the monzonite and shonkinite-porphyries has been added. The fine-grained rocks are divided as formerly into aplitic and lamprophyric series, the former subdivided on the basis of habit, the latter on the geological association and ferromagnesian constituents. Much of this description has been rewritten. The additional section on the camptonitic, monchiquitic, and alnoitic rocks emphasizes their genetic and geological association with the deep-seated rocks of the alkali series and this relationship is accentuated by the introduction of a number of analyses and an Osann diagram.

The discussion of the *effusive rocks* has largely been rewritten with a marked increase in the chemical descriptions which are supplemented by the introduction of many new analyses. The chief changes of view-point occur in the expansion and elaborated classification of the alkali rocks and in the addition of a lamprophyric group of effusive rocks analogous to those distinguished among the dike rocks. The keratophyres are now classed with the porphyries of the lime-alkali series because of their geological association, although it is recognized that by mineralogical and chemical composition they are often practically identical with rocks of the alkali series.

The section on the *trachyandesites* is entirely rewritten and the line of separation between them and the normal dacites and andesites is emphasized by the introduction of numerous analyses and an Osann diagram. The treatment of the *basalts* and *melaphyres* remains with little modification, the author still holding to the distinction of the 3 types on the basis of age, although the citation of examples, e.g., the Mesozoic diabases of the United States, is manifestly contrary to the basis of classification adopted. The correlation of the trachydolerites as the effusive form of the essexite-magma is no longer maintained, the view being expressed that their systematic position must be postponed pending the accumulation of additional information.

The lamprophyric effusive rocks are characterized by their low content of alumina and the almost constant predominance of magnesia over lime. The erection of this new division is based upon the conception that the surface equivalents of the more acid rocks are really more aplitic in their composition and that one would naturally expect to find analogous lamprophyric equivalents as well. To this division are assigned the verite, fortunite, and jumillites of Osann, the orendite-madupite group (and Prowersite) of Cross, the euktolite, coppaelite, absarokite, selagite, and sanukite.

Part II, devoted to the "Sedimentary Rocks," remains practically

unchanged beyond minor additions to bring the work up to date. The treatment of the carbonate rocks is somewhat expanded by a discussion of the *marls*, and the origin of *oölites*, and the origin of *dolomites*. The origin of the oölitic iron ores is also discussed in an additional section. The changes in organic matter by which coal and oil are formed are classified in accordance with Potonié's recent paper.

Part III. The third part, dealing with the "Crystalline Schists," has been thoroughly revised and brought down to date without any serious modification. Greater emphasis is laid on the chemical composition as an indication of the character of the original rock and here and there the discussion is an application of physical-chemical conclusions to the interpretation of the phenomena. Reference is made to the schistosity developed by crystallization under pressure as described by Riecke and the terminology is modified by the introduction of the terms proposed by Becke. In the descriptive portion no change is made in the systematic treatment, beyond the introduction of a few new names, such as the *myrmekite* of Sederholm, the *astochite-gneiss* of Belowsky, and the *sagvaudite* of Pettersen.

While the book as a whole is probably the best elementary textbook in descriptive petrography because of the clear style and comprehensive treatment of the subjects, it must be regarded as falling short of the ideal in the minds of all who find occasion to criticize the continental viewpoint, which has in large measure been developed through the writings and teachings of Rosenbusch. The criticisms against the validity of the dike rocks and the Kern theory are too well known to need restatement. There are, however, numerous inconsistencies in the systematic carrying-out of the underlying views which should be eliminated. For example, the element of age is discarded in the general discussion but frequently appears in the definitions or descriptions of the various rocks. There is likewise ground for criticism in the combined use of geological and petrographical criteria in classification which leads to the separating of rock like the keratophyres from the alkali rocks from which they are admittedly indistinguishable in chemical and mineralogical composition and in texture. A third criticism in systematic treatment is that already referred to in the handling of the charnockite and anorthosite series and the relative disregard of the silica content in the chemical discussion by the use of the Osann diagrams. It is a subject for regret that this excellent textbook cannot be translated and still more that there is no equally satisfactory work by an American author.

Edward B. Mathews

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MAGMATIC DIFFERENTIATION IN HAWAII

REGINALD A. DALY
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INTRODUCTION

Though the Hawaiian Islands are largely basaltic, it is already apparent that they contain igneous types of considerable petrographic diversity. The species so far discovered range from ultra-femic basalts and intrusive porphyry, with less than 46 per cent of silica and less than 2 per cent of alkalies, to the phonolitic trachyte of western Hawaii, with 62 per cent of silica and more than 13 per cent of alkalies. No sediments of the ordinary silicious kinds appear to enter into the composition of the islands or of their basement. Acid crystalline rocks of the gneissic or granitic order

also seem to play no rôle in the petrogenesis of the archipelago. Hence, some of the chief complications in the history of igneous magmas which have invaded the continental plateaus, that is, complications due to the assimilation of such highly varied country-

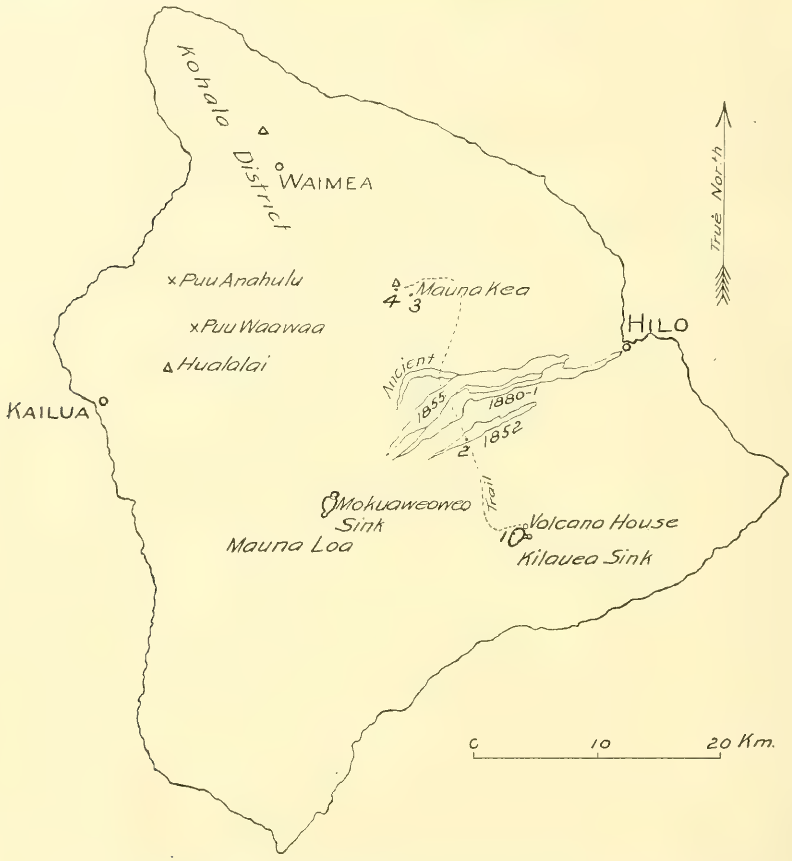

FIG. 1.—Locality map, showing positions of some of the dated lava flows in Hawaii; also original localities of specimens chemically analyzed (dots numbered 1 to 4): 1, gabbro of Uwekahuna laccolith; 2, olivine basalt of 1852 flow; 3, andesitic basalt; 4, trachydolerite.

rocks, here seem to be absent. This relative simplicity of conditions makes the petrogenesis of a deep-sea archipelago worthy of attention quite independently of its own intrinsic importance. The problem of origin here becomes largely, though not altogether,

a matter of pure differentiation. An inspection of the results so far attained in Hawaiian petrography clearly suggests the nature of the local primitive magma, namely, basalt, and shows the march of magmatic differentiation in the main island, from that parent species to the less voluminous rock-types which have so far been discovered.

The first part of this paper is devoted to a description of rock-types forming part of a collection made by the writer in 1909. From the facts won in that reconnaissance, and from those already published in the writings of J. D. and E. S. Dana, of Lyons, Phillips, Silvestri, Cohen, Möhle, Maxwell, C. H. Hitchcock, Brigham, Dutton, Cross, and others, an induction has been made as to the probable origin of the rock species in Hawaii. A brief statement of the reasoning on which this tentative conclusion is based occupies the second part of the paper.

The four new rock analyses and the analysis of phenocrystic olivine were made by Mr. G. Steiger, chemist of the United States Geological Survey. For these excellent data the writer's sincere thanks are due to him, and to Dr. G. O. Smith, the Director of the Survey, who generously acceded to the request that this work should be undertaken by the able experts of the government laboratory.

SPECIAL PETROGRAPHY

Porphyritic gabbro of the Uwekahuna laccolith.—About two hundred meters north of the Uwekahuna triangulation station, the western wall of the Kilauean sink exhibits a patch lighter in color than the average rock in the cliff. This patch is visible from the Volcano House and the writer made an early visit to this part of the sink. (See locality marked "1" in Fig. 1.) Nearing the place, it was observed that the light-tinted rock was more massive than the lavas above and below it. Large blocks of the rock had fallen from the cliff and many were plainly seen to have been derived from the lighter-colored mass, which was gabbroid in habit. With a little trouble the writer was able to scale the cliff for the vertical distance of about 20 meters, necessary to reach the lower contact. There the gabbroid rock showed a distinctly chilled phase in a contact shell several decimeters in thickness.

The upper contact was quite inaccessible, by ordinary climbing, though it might, perhaps, be reached with the aid of a rope let down from the top of the cliff. However, the coarse grain of the holocrystalline rock and the relation of the mass to the overlying ash-beds show without question that it is intrusive. The section given in the cliff is that of a laccolith, with a width of 160 meters and a maximum thickness of about 20 meters. The ash-beds above are uparched and conformable to the upper surface of the laccolith, except at the southern end, where they are cut across at a low angle by the gabbro. The massive lava flows overlying the ash beds are little, or not at all, deformed by the intrusion. Some of the upper flows may be younger than the laccolith, but it is possible that all the overlying flows are the older and that the lack of deformation in them is due to the lateral crowding and condensation of the loose ash-beds by the laccolithic magma.

The gabbroid body may conceivably represent the crystallized product of a subterranean lava stream of great length, but its deformation of the overlying ash-beds is characteristic of laccolithic intrusion and it seems just to describe the mass as a true laccolith.

The intrusive rock is dark gray in color, and slightly porous. It is porphyritic, with phenocrysts of olivine. These are so numerous that the rock appears, at first glance, to be somewhat coarsely granular. In the hand-specimen the phenocrysts appear roundish, and only rarely idiomorphic. Some of them are of the usual olive-green color, but most are iridescent on the surfaces of fracture, with the beautiful blue, green, and bronze tints of a peacock's feather. Though the rock in general is extremely fresh, this iridescence seems to be due to an incipient alteration of the olivine to serpentine, which is mixed with numerous, minute grains of iron ore.

Under the microscope, the idiomorphism of the nearly colorless, pale brownish olivine is more clearly manifest. It occurs in individuals reaching 4 mm. or more in length. The ground-mass is composed of plagioclase, augite, ilmenite, and magnetite; the chemical analysis of the rock shows that a little apatite must be present, but not a single crystal of it was demonstrable in the thin section. The ground-mass varies irregularly from the hypidio-

morphic-granular to the diabasic. The thin-tabular plagioclase, reaching 1 mm. in longest diameter, seems to be throughout the basic labradorite, $Ab_2\ An_3$. The pale brownish augite has normal habit, the major diameters reaching 0.8 or 1.0 mm. There is nothing unusual about the minerals of this rock and further descriptive details are superfluous.

An analysis of the rock, by Mr. G. Steiger, gave the result shown in col. 1 of Table I.

TABLE I

	1	1*a*	2
SiO_2	46.59	.777	48.13
TiO_2	1.83	.023	.87
Al_2O_3	7.69	.075	6.50
Fe_2O_3	2.20	.014	2.01
Cr_2O_3	.13	.001	.....
FeO	10.46	.145	11.73
MnO	.18	.002	.08
NiO	.12	.001	.....
MgO	21.79	.545	21.01
CaO	7.41	.132	6.17
Na_2O	1.33	.022	1.15
K_2O	.28	.003	.58
H_2O-	.04	....	1.62
H_2O+	.37	....	
P_2O_5	.11	.001	.15
CO_2	None	....	.....
SO_3	None	....	.....
BaO	None	....	.....
SrO	None	....	.....
ZrO_2	None	....	.....
	100.53		100.00
Sp. gr.	3.001		

Calculated Norm of 1.	
Orthoclase	1.67
Albite	11.53
Anorthite	13.90
Diopside	17.48
Hypersthene	17.06
Olivine	31.22
Ilmenite	3.50
Magnetite	3.25
Chromite	.22
Apatite	.31
Water	.41
	100.55

1 Porphyritic gabbro of the Uwekahuna laccolith.
1*a* Molecular proportions in 1.
2 Average analyses of three typical wehrlites.

Using the chemical analysis and the Rosiwal optical method, the minerals have been calculated to form the following weight percentages:

Olivine	40.0
Augite	31.0
Labradorite	27.0
Magnetite and ilmenite	1.7
Apatite	.3
	100.0

In the Norm classification the rock falls in the domagnesic subrang, wehrlose, in the permiric section, wehrliase, permirlic rang, wehrlase, and section hungariare, of the dofemane order, hungarare.

According to the accepted Mode classification the rock is an ultra-femic porphyritic olivine gabbro or gabbro porphyrite. The analysis is very similar to the average of three typical wehrlites entered in Part II of Osann's *Beiträge zur chemischen Petrographie.* See column 2 of the accompanying Table I.

Ultra-femic olivine basalt, flow of 1852.—Following the trail from the Volcano House to Mauna Kea, the writer crossed the lava which, in 1852, flowed out on the Hilo slope of Mauna Loa. The trail traverses this lava at the 6,100-foot contour (see locality "2" in Fig. 1), where the flow is about 1.5 kilometers in width. The lava is of the aa or block type and much work with sledge hammers was necessary to make a trail passable even for the hardy pack-animals of the island. The broken rock is, of course, quite fresh, and its numerous olivine phenocrysts, of unusually great size and of beautiful color and brilliance, made a remarkable effect for the eye as one walked or rode over the lava. The development of phenocrystic olivine is greater in this flow than in any other seen by the writer during several hundred miles of travel in Hawaii.

The hand-specimens of the lava have a dark-gray, lithoidal ground-mass, in which the abundant, bright yellowish-green olivines are conspicuously set. As usual with the aa type of lava, the gas pores are large and irregularly distributed through the rock. They were elongated and flattened during the flow of the stiffening lava and the longer diameters of the pores reach three or more centimeters in length. The idiomorphism of the olivine is often manifest to the unaided eye, and is still more evident under the microscope. The individual crystals are often more than one centimeter in diameter. No other mineral is phenocrystic.

The microscope shows a rather surprising contrast in the grain of the ground-mass, which is of diabasic structure, with thin tables of plagioclase, seldom over 0.1 mm. in length, separated by augite granules of even smaller diameters. Magnetite and prob-

ably ilmenite form the only other visible constituents, though a little apatite must occur. No glass and no sulphide mineral could be found in the ground-mass.

The olivine includes a little magnetite, in small euhedral and anhedral crystals. A few brown, roundish inclusions may be glass. In thin section the olivine is nearly colorless with a gray tinge. It was easily isolated and then freed of impurities except for the minute inclusions described. Its analysis, by Mr. Steiger, gave the following result:

		Mol.	Calculated Composition	
				Per cent
SiO_2	40.42	.670	Forsterite	82.29
TiO_2	.08	.001	Fayalite	15.94
Al_2O_3	.32	.003	Tephröite	0.20
Fe_2O_3	.15	.001		
Cr_2O_3	.18	.001		98.43
FeO	11.44	.159	Anorthite	0.97
MnO	.10	.001	Magnetite	0.23
NiO	.34	.005	Ilmenite	0.15
MgO	47.08	1.168	Chromite	0.22
CaO	.23	.004	NiO	0.34
	100.34			1.91
Sp. gr.	3.369		Grand total	100.34

So far as known to the writer, this is the only total analysis of any Hawaiian olivine yet made. Penfield and Forbes found 10.3 per cent of FeO in olivine collected by J. D. Dana on the southeastern shore, south of Hilo. The optical angle (2V) for this mineral was calculated to be $91^\circ\ 2'$, and the authors found that chrysolites containing about 12 per cent of FeO show a value of 90° for 2V in yellow light.[1] The olivine now described has 11.44 per cent of FeO, and hence it would be extremely difficult to be quite certain whether the mineral is positive or negative. No special work has been expended in the attempt to determine that point.

The minute plagioclase tables of the ground-mass gave maximum extinctions corresponding to the mixture $Ab_{45}\ An_{55}$. The augite is pale, practically colorless in thin section, and has no noteworthy

[1] S. L. Penfield and E. H. Forbes, *Amer. Jour. Sci.*, I (1896), 133

peculiarities. A study of the chemical and mineralogical analyses showed that it must be rich in FeO and relatively poor in MgO. The magnetite and ilmenite are abundant in the ground-mass.

Mr. Steiger's analysis of the rock gave the proportions shown in Table II.

TABLE II

	1	1*a*
SiO_2	48.57	.810
TiO_2	1.48	.019
Al_2O_3	10.51	.103
Fe_2O_3	2.19	.014
Cr_2O_3	.10	.001
FeO	9.45	.132
MnO	.16	.001
NiO	.08	.001
MgO	17.53	.438
CaO	8.06	.144
Na_2O	1.59	.026
K_2O	.34	.004
H_2O-	.10	....
H_2O+	.37	....
P_2O_5	.19	.001
CO_2	None	....
	100.72	
Sp. gr.	3.065	

Calculated Norm	
Orthoclase	2.22
Albite	13.62
Anorthite	20.29
Diopside	15.11
Hypersthene	23.98
Olivine	18.49
Ilmenite	2.89
Magnetite	3.25
Apatite	.31
Water	.47
	100.63

1 Ultra-femic olivine basalt, lava flow of 1852.
1*a* Molecular proportions in 1.

Using the Rosiwal method, checked by the analyses, the Mode (weight percentages) was calculated to be:

Olivine	32.0
Augite	27.0
Labradorite	35.7
Ilmenite	2.5
Magnetite	2.5
Apatite	.3
	100.00

Assuming the probable values of the specific gravity for each mineral, the specific gravity of the rock was calculated to be 3.16, which agrees satisfactorily with the actual value, 3.065, found by the proper weighing of coarse powder of the rock.

In the Norm classification the rock enters the hitherto unnamed

domagnesic subrang, in the permiric section and permirlic rang of the dofemane order, hungarare. If a name for this type in the Norm classification is desired, the subrang may be called *hilose*, from the name of the chief port of the island, Hilo. The corresponding names for the rang-section and rang would be *hiliase* and *hilase*. The hitherto unnamed section of the order may be called *hawaiiare*.

According to the Mode classification the rock is an ultra-femic olivine basalt of an extreme type. In both chemical and mineralogical analyses it approaches the still more abnormal type represented in the Uwekahuna laccolith.

Andesitic basalt, upper slope of Mauna Kea.—On the eastern side of Mauna Kea, from the 6,000-foot contour to about the 12,000-foot contour, the abundant lava flows seem to be very uniformly composed of a rock species which is intermediate between typical olivine basalt and a true augite andesite. These lavas are almost entirely of the aa or blocky type; pahoehoe surfaces are only locally developed and, within the area described, seldom, if ever, show the perfection so often illustrated in Mauna Loa. Among the specimens collected, one taken at the 11,000-foot contour (see locality "3" in Fig. 1), 4,500 meters S 75° E of the summit of Mauna Kea, was selected for chemical analysis. Its description would doubtless apply, with but unimportant change, to the average lava of all this part of the great volcano.

The rock is dark gray, fresh, and strongly vesicular, again showing the great irregularity in the size and distribution of the vesicles, which is usual with aa lava. The only minerals microscopically visible in the dense ground-mass are a few phenocrysts of yellowish-green olivine and tabular plagioclase, with maximum diameters of 2 mm. and 3 mm. respectively. In thin section a few idiomorphic phenocrysts of augite, reaching 1 mm. in length, are to be seen. Estimates made by the Rosiwal method show that the olivine phenocrysts form no more, or little more, than one per cent of the rock by weight, and that the augite phenocrysts occur in about the same proportion. The very abundant plagioclase phenocrysts have cores averaging about $Ab_1 An_1$ in composition. They are often surrounded by a very thin shell of oligoclase

averaging $Ab_7 An_3$, as indicated by zero extinction on (010). That shell is surrounded by a still thinner, outermost shell, which gives an extinction of about $+5°$ on (010) and is either a more acid oligoclase or else orthoclase.

The ground-mass has a pilotaxitic to diabasic structure and consists of plagioclase, augite, and magnetite, each in high proportion. A few round granules of olivine may also be discerned. The plagioclase is often zoned, with a somewhat larger relative development of the acid shells. Again, the outermost shell may, in many cases, be alkaline feldspar, but the very fine grain prevents its actual demonstration. No sulphide mineral was visible in the rock.

Mr. Steiger's analysis yielded the result shown in column 1 of Table III.

TABLE III

	1	1a	2
SiO_2	49.73	.829	49.19
TiO_2	3.05	.038	1.72
Al_2O_3	16.39	.161	14.02
Fe_2O_3	7.58	.048	5.62
FeO	3.98	.056	8.68
MnO	.23	.003	.54
MgO	4.06	.101	6.42
CaO	7.17	.128	9.10
Na_2O	4.12	.066	3.24
K_2O	1.93	.020	1.04
H_2O-	.81	....	.74
H_2O+	.54	....	
P_2O_5	.84	.006	.28
CO_2	None	....	.....
BaO	.03	....	.....
SrO	None	....	.....
NiO	.04	....	.....
Cr_2O_3	None	....	.....
ZrO_2	.03	....	.....
SO_3	None	....	.....
S	None	....	.....
	100.53		100.59
Sp. gr.	2.911		

Calculated Norm of 1	
Quartz	1.86
Orthoclase	11.12
Albite	34.58
Anorthite	20.85
Diopside	6.78
Hypersthene	6.80
Ilmenite	5.78
Magnetite	4.87
Hematite	4.32
Apatite	1.86
Water, etc.	1.45
	100.27

1 Andesitic basalt, lava flow at 11,000-foot contour of Mauna Kea.
1a Molecular proportions in 1.
2 Average composition of normal Hawaiian basalt.

By the Norm classification the rock enters the dosodic subrang, andose, in the alkalicalcic rang, andase, of the dosalane order, germanare.

According to the Mode classification, it is an andesitic basalt, transitional in type between olivine basalt and augite andesite. Its specific gravity was determined on a specimen which had been coarsely powdered to avoid an error due to the porosity of the rock. For comparison the calculated average for the basalt of Hawaii is given in column 2.

Trachydolerite of summit flows, Mauna Kea.—Brigham and others long ago noted the occurrence of "clinkstone" at the top of Mauna Kea, and the present writer had opportunity to make some study of this rock in place during the 1909 reconnaissance. Near the 13,000-foot contour, he found several flows of lava of much lighter color than the staple olivine basalts of Hawaii, or than the abundant andesitic basalt just described. These flows all seem to be short, generally less than one kilometer in length. Their terminal scarps have been little affected by frost or other weathering agents, and the steepness of these scarps indicates a notable degree of viscosity during the outflow. In some cases these flows could be seen to have emanated from the fissures in the summit cinder-cones. Though the pyroclastic material of the cones is generally altered (to deep brown and red tints), it appears to be chemically identical with that composing the always fresh, light-colored flows.

The "clinkstone" habit is due largely to a noteworthy lack of vesicles in the lava. Though some large gas-pores always occur in the thin surface shell of each flow, its interior is often nearly or quite free from even small pores. This homogeneity of the rock is, doubtless, chiefly responsible for the extremely sonorous, metallic sound given out when the lava is broken by the hammer.

For special examination, typical specimens were taken from a flow which issued from the eastern flank of the cinder-cone named "Poliahu" on the government map, at a point about 350 meters north of the summit pond. The description of the lava may be based on one specimen, which has been chemically analyzed.

The rock is of a fairly light, slate-gray color, is non-porous, very dense, but holocrystalline. A few thick tables of plagioclase, from 1 mm. to 2 mm. in length, represent the only constituent determi-

nable to the unaided eye. There is merely a hint at flow-structure, registered in a rude parallelism of these phenocrysts.

Under the microscope it is seen that a few, small, anhedral olivines, and somewhat more numerous augite crystals—none, in either case, surpassing 1 mm. in greatest diameter—are to be added to the abundant plagioclase (averaging labradorite, $Ab_1 An_1$) in the list of phenocrysts.

The ground-mass shows a confused crystallization of augite, magnetite, and apatite, in a dominant felt of feldspar. A few grains of an allanite-like mineral, pleochroic in tones from deep brown to pale greenish-brown, form the only other accessory material. No sulphide is visible in thin section. Most of the ground-mass feldspar is plagioclase—acid labradorite or basic andesine—twinned on the albite law. Another feldspar arranged interstitially in relation to the plagioclase has the low double refraction and lack of twinning characteristic of orthoclase. This mineral occurs in such minute individuals that a full demonstration of its nature has not been possible. Many of the labradorite phenocrysts are surrounded with shells of alkaline feldspar with extinctions on (010) ranging from $+5°$ to $+9° 30'$, suggesting orthoclase and soda-orthoclase, and it is very probable that both of these represent the last product of crystallization in the ground-mass. The total alkaline feldspar does not form much more than 15 per cent of the rock by weight.

Mr. Steiger's analysis of this rock gave the proportions shown in col. 1 of Table IV.

By the Norm classification the rock is to be referred to andose, the same subrang as that calculated for the andesitic basalt just described. According to the Mode classification, this rock, containing an essential amount of alkaline feldspar, is best included among the trachydolerites, as defined by Rosenbusch, though near the basaltic end of that series. In column 2 of Table IV the average of the 34 analyses of trachydolerites, named as such in the last edition of Rosenbusch's *Elemente der Gesteinslehre*, is given for comparison. Column 3 gives Lyons' analysis of a more alkaline, less femic, trachydoleritic type from the neighboring volcanic pile in Kohala.[1]

[1] A. B. Lyons, *Amer. Jour. Sci.*, CLII (1896), 424.

Lherzolitic nodules in the summit lavas of Mauna Kea.—The chief difference between the andesitic basalt and the trachydolerite is mineralogical; orthoclase is an essential constituent in the latter, and has wholly, or almost wholly, failed to individualize in the basalt. The two types are almost alike chemically. They also resemble each other in carrying rather numerous ultra-femic nodules of all sizes up to 10 cm. in diameter. These are always rounded and usually roughly spherical, of coarse grain, and of a

TABLE IV

	1	1a	2	3
SiO_2	50.92	.849	49.20	58.06
TiO_2	2.55	.032	1.68	1.88
Al_2O_3	17.59	.173	16.65	18.21
Fe_2O_3	3.80	.024	4.76	4.87
FeO	6.69	.093	5.36	2.01
MnO	.20	.001	.55	.36
MgO	3.90	.097	4.43	1.59
CaO	6.97	.125	7.74	3.29
Na_2O	4.28	.069	4.54	6.12
K_2O	1.86	.020	3.19	2.75
H_2O-	.35	....	1.30	.....
H_2O+	.79	....		.....
P_2O_5	.40	.003	.60	.65
CO_2	None	....	.....	.....
NiO	None	.....	.....	.....
Cr_2O_3	None	....	.....	.....
CuO, etc.	.....	.....	.....	.20
	100.30		100.00	99.99
Sp. gr.	2.761			

Calculated Norm of 1	
Orthoclase	11.12
Albite	36.16
Anorthite	23.35
Diopside	6.98
Hypersthene	7.21
Olivine	2.98
Ilmenite	4.86
Magnetite	5.57
Apatite	.93
Water	1.14
	100.30

1 Trachydolerite, lava flow at 13,000-foot contour on Mauna Kea.

1a Molecular proportions in 1.

2 Average of 34 analyses of trachydolerites named as such in the third edition of Rosenbusch's *Elemente der Gesteinslehre.*

3 "Andesite" from Waimea, Kohala district, in northwestern Hawaii.

dark green or brownish-green color. They seem to be rather uniformly composed of dominant olivine, much diallage, subordinate or accessory plagioclase, and a little magnetite or ilmenite. Apatite has not been demonstrated in thin section.

The nodules occur in the trachydolerite of the cinder-cones as well as of the adjacent flows. In a few cases observed, the nodules of the cinder-cones formed ellipsoidal bodies without any adhering trachydolerite, as if each of these nodules represents a solid mass exploded out of the vent and freed from liquid magma by the

violence of the explosion. More generally, the nodules occur in projectiles largely composed of the normal trachydolerite. The specific gravity of one ellipsoidal nodule about 8 cm. in length was found to be 3.316; it is almost entirely free from feldspar.

The nodules inclosed in lava are best displayed in the frost-riven felsenmeer surrounding the summit pond. One of these was sectioned and specially studied. The plagioclase was found to have the composition of acid anorthite, $Ab_1 An_9$. A few small tables of the feldspar and rare granules of olivine are inclosed in the diallage, but in general, the anorthite is interstitially developed between the olivine and diallage crystals, which seem to have crystallized nearly simultaneously and after the iron ore. The pyroxene is much more often idiomorphic than is the olivine. The specific gravity of this nodule is 3.111.

The Rosiwal method afforded the following estimate of its weight percentages:

Olivine	62
Diallage	26
Anorthite	11
Magnetite and ilmenite	1
	100

Assuming the olivine to have the same composition as the olivine in the lava flow of 1852, and the diallage to have the average composition of basaltic augite,[1] the nodule was calculated to have, approximately, the composition shown in column 1 of Table V.

TABLE V

	1	2
SiO_2	43.4	43.78
TiO_2	.3	.12
Al_2O_3	5.5	5.02
Fe_2O_3	1.5	5.18
FeO	8.8	4.77
MgO	32.8	33.08
CaO	7.4	6.62
Na_2O	.3	1.06
$MnO+K_2O+P_2O_5$	....	.37
	100.0	100.00

[1] See *Journal of Geology*, XVI (1908), 410.

Column 2 gives the average composition of four typical lherzolites.[1] In spite of any uncertainties as to the exact compositions of the femic minerals, it is clear that the nodule is, chemically, a lherzolite.

The writer believes that these nodules are not exotic, but represent segregations in their respective magmas just as truly as do the olivine phenocrysts. Easy transitions in size are to be found, in the field, between large, single phenocrysts of olivine and the largest olivine nodules observed.

Notes on other lava flows, studied microscopically.—On the trail from the Volcano House to Mauna Kea, at about the 6,000-foot contour (see Fig. 1), the flow of 1880–81 was found to be olivine basalt of the pahoehoe type. The adjacent flow of 1855 is similarly composed but has local aa phases. Still farther north the trail crosses the "ancient flow" shown on the government map (marked "ancient" in Fig. 1); this is an olivine basalt with typical aa habit. At the wagon-road between Waimea and Kailua, the great flow of 1859 is an olivine-poor to olivine-free basalt with both aa and pahoehoe phases.

Projected blocks at Kilauea and Hualalai.—E. S. Dana has already described the common, basaltic types of rock represented in the solid projectiles thrown out in the rare explosions which have occurred at Kilauea.[2] The present writer has made a microscopic examination of seven different specimens of the projectiles sampled at intervals along the edge of the Kilauean sink from Uwekahuna to Kilauea Iki. All of them are holocrystalline and they are non-vesicular or else nearly free from pores. In the coarser blocks the pores are true miaroles, into which the feldspar and augite, showing crystal facets, have grown. The rock species included in this small collection are: basalt poor in olivine; typical olivine diabase; olivine-free diabase; and a typical, relatively coarse-grained olivine-free gabbro.

Of these, the gabbro is the only type worthy of special remark. It composes several of the projectiles occurring on the road from the Volcano House to Kilauea Iki, near Waldron's Ledge. The

[1] See *Proc. Amer. Acad. Arts and Sciences*, XLV (1910), 226.

[2] See J. D. Dana, *Characteristics of Volcanoes* (New York, 1891), 344.

visible blocks are all angular, quite fresh, and 20 to 50 cm. in greatest diameters. No olivine is visible in the fairly dark-gray, granular rock, either in the field or under the miscroscope. The essential constituents are labradorite, $Ab_2 An_3$, and a strongly tinted, greenish-brown, non-pleochroic augite, with an unusual amount of iron ore, probably ilmenite. Apatite in needle form is very abundant; therein this rock contrasts with nearly every Hawaiian rock so far studied in thin section. The stout augite prisms, which lack the diallage parting, reach 4 mm. in length; the thick tables of labradorite are often 5 mm. in length and the plates of ilmenite measure 1 mm., or less, to 5 mm. in length. The structure of the rock is not basaltic or diabasic, but typically hypidiomorphic-granular.

On the summit of Hualalai the writer sampled three projected blocks which occur in a thin pyroclastic deposit veneering this lava-formed (olivine-basalt) volcano. Two of them are holocrystalline equivalents of the normal olivine basalt of the island. The third is a coarsely granular rock almost identical in composition and grain with the type forming the laccolith at Uwekahuna; it is an ultra-femic gabbro, with high idiomorphism in the abundant olivine.

Average composition of Hawaiian basalt.—Of the extant analyses of the basalts from the main island, nineteen, which were made from fresh and typical material, have been selected for the purpose of computing the average composition of the dominant rock type of the island. Most of these analyses are quoted in C. H. Hitchcock's *Hawaii and Its Volcanoes* (Appendix D). Ten are taken from O. Silvestri's paper in the *Bolletino del R. Comitàto Geologico Italiano* (XIX [1888], 185); four from E. Cohen's paper in the *Neues Jahrbuch für Mineralogie*, etc. (1880; II, 23); and four from A. B. Lyons' paper in the *American Journal of Science* (II [1896], 424). Mr. Steiger's analysis of the 1852 flow and his analysis of the chemically similar porphyry forming the small laccolith at Uwekahuna, Kilauea, are also included, making twenty analyses in all.

The calculated average is shown in the first column of Table VI, where the second column gives the writer's result in averaging

198 analyses of fresh basalts taken from Osann's great compilation for the world (analyses published between 1884 and 1900).

TABLE VI

	Average Hawaiian Basalt	Average World Basalt
SiO_2	49.19	49.06
TiO_2	1.72	1.36
Al_2O_3	14.02	15.70
Fe_2O_3	5.62	5.38
FeO	8.68	6.37
MnO	.54	.31
MgO	6.42	6.17
CaO	9.10	8.95
Na_2O	3.24	3.11
K_2O	1.04	1.52
H_2O	.74	1.62
P_2O_5	.28	.45
	100.59	100.00

The close correspondence of the two averages is obvious at a glance. In fact, it has been found that the greater the number of reliable analyses included, the nearer the Hawaiian average approaches the world average. Though perfect averages might show the former to be slightly the more femic of the two, it is certain that the staple igneous type in the mid-oceanic Hawaii are chemically very similar to the average basaltic magma poured out on the continental plateaus.

THEORETICAL CONSIDERATIONS

Origin of the ultra-femic types.—In columns 1 and 2 of Table VII the analyses of the Uwekahuna laccolith and of the 1852 lava flow are respectively entered. Column 3 gives the mean of these two analyses. Column 5 gives the average analyses of four typical lherzolites, calculated as water-free. Column 6 shows the calculated composition of the average Hawaiian basalt, while column 4 gives the mean of columns 5 and 6.

A comparison of the markedly similar columns 3 and 4 suggests that the ultra-femic magmas of the island are due to the mixture of a large amount of the ferromagnesian and cafemic (calcium-iron-magnesium) constituents of the basalt with the average basalt itself, though, of course, not necessarily in absolutely equal pro-

portions for the two parts of the mixture. Such a mixture could occur in the main volcanic vents at great depth, provided that the ferromagnesian and cafemic molecules settled down from the magma in the upper part of the vent, where gravitative differentiation was taking place.

This explanation of the ultra-femic phases is favored by the consideration that no fact in the field relations opposes the assumption of a very deep, direct source for these heavy magmas. The flow of 1852 emanated from a fissure in Mauna Loa, about 1,300 meters below the top of the main conduit of the island; and the laccolithic body exposed in the wall of Kilauea is 3,000 meters

TABLE VII

	1 Laccolithic Porphyry	2 Flow of 1852	3 Mean of 1 and 2	4 Mean of 5 and 6	5 Average Lherzolite	6 Average Hawaiian Basalt
SiO_2	46.59	48.57	47.58	46.65	43.78	49.19
TiO_2	1.83	1.48	1.66	.92	.12	1.72
Al_2O_3	7.69	10.51	9.10	9.52	5.02	14.02
Fe_2O_3	2.20	2.19	2.20 } 12.15	5.40 } 12.12	5.18	5.62
FeO	10.46	9.45	9.95	6.72	4.77	8.68
MnO	.18	.16	.17	.30	.06	.54
MgO	21.79	17.53	19.66	19.75	33.08	6.42
CaO	7.41	8.06	7.74	7.86	6.62	9.10
Na_2O	1.33	1.59	1.46	2.15	1.06	3.24
K_2O	.28	.34	.31	.67	.30	1.04
H_2O	.41	.47	.44	.37	.....	.74
P_2O_5	.11	.19	.15	.15	.01	.28
Cr_2O_3 etc.	.25	.18	.21	.....	.....	.....
	100.53	100.72	100.63	100.46	100.00	100.59

below the same level. In either case, the level in the conduit where it was tapped to form the erupted body may have been several kilometers still lower down in that conduit.

Origin of the less femic types.—The hypothesis that the ultra-femic rocks represent the products of mixture of the average basalt with the ferromagnesian and cafemic substances (more specifically the molecules represented in the phenocrysts of the normal basalt) settled down from higher levels in the main Hawaiian vent, implies that more salic and more alkalic magma is formed at those higher levels. According to the thoroughness of the gravitative differentiation, the less dense magmas would vary in the degree in which

they would be more salic and alkalic than the parent basalt. As a matter of fact, a goodly number of such derived magmas seem to be represented in Hawaii. Table VIII, columns 2–6, shows the chemistry of the principal types to which this mode of origin may be, at least tentatively, ascribed.

TABLE VIII

	1	2	3	4	5	6
SiO_2	49.19	49.73	50.92	58.06	61.64	62.19
TiO_2	1.72	3.05	2.55	1.88	.....	.37
Al_2O_3	14.02	16.39	17.59	18.21	.....	17.43
Fe_2O_3	5.62	7.58	3.80	4.87	.....	1.65
FeO	8.68	3.98	6.69	2.01	.....	2.64
MnO	.54	.23	.20	.36	.....	.32
MgO	6.42	4.06	3.90	1.59	.....	.40
CaO	9.10	7.17	6.97	3.29	.....	.86
Na_2O	3.24	4.12	4.28	6.12	.....	8.28
K_2O	1.04	1.93	1.86	2.75	.....	5.03
H_2O	.74	1.35	1.14	.....	.....	.53
P_2O_5	.28	.84	.40	.65	.....	.14
NiO, etc...	.....	.10	.....	.20	.....	.09
	100.59	100.53	100.30	99.99	.....	99.93
Sp. gr.....	.....	2.911	2.761	.....	.....	2.627††

†† Determined from hand-specimen collected by the writer. All three rocks for which specific gravities are given, are holocrystalline.

1 Average analysis of twenty basaltic types in Hawaii.

2 Andesitic basalt of Mauna Kea.

3 Trachydolerite of summit, Mauna Kea.

4 "Andesite" (trachydolerite) of Waimea, Kohala district (analyzed by A. B. Lyons, *Amer. Jour. Sci.*, II [1896], 424).

5 "Augite Andesite from the Sandwich Islands" (silica determined by E. Cohen, *Neues Jahrbuch für Mineralogie, etc.* [1880; II, 38]).

6 Phonolitic trachyte of Puu Anahulu (described by W. Cross, *Journal of Geology*, XII [1904], 510).

On p. 53 of the paper by Cohen, for which the reference has been given, it is stated that in the rock collection there described, four other occurrences of "typical augite andesites" in Hawaii are represented. Two of the specimens were taken on Mauna Kea; the other two were collected on this island, but the labels failed to give their exact localities. No analyses were made of these specimens, but, of course, one may trust Cohen's well-known skill in diagnosis and place all four rocks among the more salic types of Hawaii.

From the table it seems clear that the strongly alkaline trachyte

of Puu Anahulu and the "andesite" of Waimea are consanguineous and that transitional types connect them with the distinctly subalkaline, normal basalt of the island. The steady decrease of the iron oxides, magnesia, and lime, and the corresponding increase in silica, alumina, and alkalies are as systematic as could be expected in a syngenetic series derived by the process of differentiation already in part described.

The norms calculated for the analyzed types tell the same story. They are summarized in the form here given:

	Average Hawaiian Basalt	Andesitic Basalt of M. Kea	Trachydolerite of M. Kea	Andesite of Waimea	Trachyte of Puu Anahulu
Salic........	53.94	68.41	70.63	85.09	86.74
Femic.......	45.76	30.41	28.53	14.75	12.45

Calculation shows that the alkalic members of the series were probably not formed by a mere subtraction of ferromagnesian and cafemic, phenocrystic material from the normal basaltic magma. On the other hand, a positive addition of the alkalies seems to have occurred when the more silicious types were developed.

The concentration of the alkalies in the upper part of an initially basaltic vent may conceivably be due to two principal causes. In the first place the feldspathic or feldspathoid matter of the basalt might individualize in liquid phases or as plastic or rigid crystals, and, because of the low density of any of these phases, rise in the magma column, just as the individualized olivine or augite (in liquid or solid phases) must sink. Or, secondly, the volcanic vent may become temporarily enriched in emanating gases, which, as they rise, bring the alkalies with them in loose combination.

Of these two possible causes the partial control by rising volatile substances seems to be specially clear in intrusive bodies. The writer has suggested that most of the alkaline rock types have been derived from subalkaline magma through the solution of limestone or other carbonate-bearing sediments.[1] Thereby the subalkaline magma is not only fluxed and so prepared for drastic

[1] *Bulletin Geological Society of America*, XXI (1910), 87–118.

differentiation, but the carbon dioxide introduced from the sediment carries the alkalies with it as the gas rises through the magma. An instructive series of experiments by Giorgis and Gallo bear on this suggestion. They mixed the powders of various recent Vesuvian lavas with water, and passed a current of carbon dioxide through each mixture for a period of two months. Analyses showed that the powders lost, on the average, 37 per cent of the soda originally contained, the remaining constituents being but little altered in amount.[1] At high temperatures the upward transfer of the alkali would presumably be much more rapid.

In the case of the Puu Anahulu trachyte or in that of the Waimea "andesite," the principal factor in the differentiation may have been the solution of coral or foraminiferal limestones, such as are known to be interbedded with the older lavas of the archipelago. That the normal magma of the archipelago has been locally affected by such solution is suggested by the occurrence of melilite and nephelite in the basalts of Maui and Oahu, the melilite indicating an excess of lime and the nephelite showing such desilication of the salic part of the magma as is expected when it dissolves foreign lime. The carbon dioxide entering the primary basaltic magma because of this solution of sedimentary rock would belong in the "resurgent" class of emanations. A special concentration of juvenile carbon dioxide in a basaltic vent would, in an analogous way, tend to concentrate the alkalies of the basalt at the top of the vent.

This hypothesis, that the decidedly alkaline rocks of Hawaii have been derived from the normal, subalkaline basalt through gravitative differentiation in the volcanic conduits, is supported by the intimate field-association of the two classes of rocks, and by the fact that the alkaline bodies are all of very small volume as compared with the known mass of normal basalt in Hawaii. The first-mentioned relation is obvious; the second is already clear, even though the island has been covered only by reconnaissance journeys. It is practically certain that the trachyte of Puu Anahulu and vicinity, the most salic type and one very conspicuous in the field, can be exposed at but very few and small

[1] G. Giorgis and G. Gallo, *Gazetta* (1906) [I], 137.

areas at the present surface of the island. As expected on the hypothesis, the alkaline types more nearly approximating the average basalt in composition are much more voluminous than the extreme phonolite-trachyte member of the series. In Mauna Kea, at any rate, the trachydoleritic representative of the alkaline species seems to be confined to the summit plateau of the volcano, that is, to the region where it should occur if it were due to the vertical differentiation of the basalt.

On the other hand, the dominant rocks on the broad summits of Mauna Loa and Hualalai, and of Haleakala, in Maui, are normal basalts, often rich in phenocrystic olivine.[1] There is no doubt that the conditions were unfavorable to important differentiation during most of the time engaged in the building of these giant volcanoes. Similarly, the lava of the active vent at Kilauea is basaltic and apparently has always been of that normal composition.

One reason for this contrast with Mauna Kea in its latest stage is probably connected with difference of temperature, for the differentiation of any of the commoner earth magmas seems to take place only within a comparatively narrow temperature range occurring just above the "point" of solidification. That the average temperature of the latest Mauna Kea vents was actually lower than that characteristic of the active Mokuaweoweo on Mauna Loa is suggested: (*a*) by the smaller size of the pipes on Mauna Kea; (*b*) by the far greater abundance of pyroclastic material on Mauna Kea; and (*c*) the correlative high viscosity of the short, stubby flows on Mauna Kea. The latter were more viscous than the average flow on the summit of Mauna Loa, not merely or chiefly because of difference in chemical composition.

But a probably much stronger control is to be found in the

[1] E. S. Dana describes a group of "clinkstone-like basalts" (specific gravity, 2.82–3.00), free from olivine or very poor in it, which were collected at the summit of Mauna Loa. These may represent incipient differentiation even at Mokuaweoweo. Another, highly olivinic group of basalts (specific gravity 3.00–3.20) are, however, associated in great volume. (See J. D. Dana, *Characteristics of Volcanoes* [New York, 1891], p. 319.) The present writer found a similar variation in the basalts at the summit of Haleakala, which are cut by dikes of compact, olivine-free rock suggestively like the trachydolerite of Mauna Kea.

inhibiting convection which is so powerful in highly fluid columns like those of the active Mokuaweoweo or Kilauea. In a paper published in the current volume of the *Proceedings of the American Academy of Arts and Sciences*, the writer has indicated the probable cause of the very energetic stirring visible in the Kilauea lava column. The action is there called "two-phase convection," as it depends on vesiculation of the lava in depth. The gas-bubble phase is formed through supersaturation of the liquid with juvenile volatile matter. A small amount of vesiculation in depth must lend much buoyancy to the magma, which rushes up the conduit in periodic gushes; its place is taken by sinking magma that has been rendered more dense by the escape of its included gas at the surface. This type of stirring—incomparably more effective than thermal convection can be in such a column—keeps the vent open by transferring the abyssal heat to the zone of radiation; and as well, tends to prevent differentiation because of the continuous, thorough mixing of components in the magmatic column. A dormant state is introduced when the special supply of gas is largely exhausted. Then two-phase convection is slowed down, and if the other conditions permit, gravitative differentiation may affect the column more or less. Revival of activity is the result of a renewed concentration of juvenile gases rising into the conduit from the feeding magma chamber. The consequent strengthening of two-phase convection means a speedy remixing of the products of differentiation in the column. Hence, in such hot vents as those at Kilauea, Mokuaweoweo, or Matavanu, outflows of highly differentiated lavas are not to be expected.

When Mauna Kea was approaching extinction, its magmatic column or columns, characterized by increasing viscosity and perhaps less charged with juvenile gases, were less stirred by two-phase convection. In relative quiet they differentiated to a slight extent, giving a trachydoleritic type as the upper, salic pole. The gases became dissipated at the craters, and the effluent lavas of this latest phase of the volcanic pile are "clinkstones" because comparatively free of gas-pores. The explosions which formed numerous cinder-cones at the summit may have been due to the inhibition and superheating of meteoric

water, as well as to the latest, violent expulsion of the juvenile gases from the increasingly viscous magma.

Little is known of the detailed geology of the Kohala district, but the abundance of cinder-cones on the heights of this other great pile suggest a differentiation history resembling that sketched for Mauna Kea. However, the strongly alkaline "andesite" of Waimea, like the phonolitic trachyte of Puu Anahulu, may represent limestone-fluxing as a leading condition for such specially advanced differentiation of the basaltic magma.

Parallel differentiation in other oceanic islands.—Weber's recent study of the Samoan lavas, including those from Savaii, shows a remarkable similarity between them and the rocks of the Hawaiian group.[1] The types already found in Savaii and in the neighboring islands include: olivine basalt, olivine-poor basalt, andesitic basalt, trachydolerite, "Alkalitrachyt," trachyte, and phonolite. "Savaii" is said to be the Samoan equivalent of the name "Hawaii." By a curious coincidence the vent of Matavanu is, among vents now active, the most perfect known analogue to Kilauea; and the volcanic mechanism seems to be practically identical in these two archipelagoes. The writer entirely agrees with Weber as to the necessity of regarding the subalkaline and alkaline rocks of each island group as syngenetic. The parallelism in the magmatic histories of Savaii and Hawaii is shown even in details, for Weber described olivine-augite nodules in the feldspar basalt of Mauga Loa, a rock which in all respects recalls the nodule-bearing, andesitic basalt of Mauna Kea.

Among the leading effusive types in Tahiti are olivine basalt, olivine-free basalt, haüynophyre, phonolite, and picrite, the description of the last-mentioned rock resembling that of the analyzed 1852 flow in Hawaii. Although basalts compose most of Tahiti, this mid-Pacific island has also furnished nephelite syenites, theralites, essexitic gabbros, and tinguaites.[2] In the Solomon islands olivine basalt and augite andesite are associated with an

[1] M. Weber, *Abhandlungen Math-phys. Klasse, Kgl. Bayerischen Akademie der Wissenschaften*, XXIV (1909), 287.

[2] A. Lacroix, *Bulletin Société géologique France*, X (1910), 91–124.

augite trachyte which is suggestively like the phonolitic trachyte of Puu Anahulu in Hawaii.[1]

Reconnaissances in Kerguelen Island show the intimate association of olivine basalt, basalt bearing olivine nodules, trachyte, and phonolite. Basalts and alkaline trachytes are the known species composing Ascension Island. St. Helena shows dominant olivine basalt and olivine-free basalt, with haüynite basalt and phonolite.

Without citing other parallels among the oceanic islands, it is now clear that the repeated association of volcanic species, ranging from olivine basalt to phonolitic trachyte or true phonolite, is not accidental. In all essential respects the argument for the gravitative differentiation of the salic types from normal basalt seems as strong for the chief Samoan island as it is for the chief Hawaiian island. It is commonly assumed that the subalkaline basalt and the alkaline phonolite originate in separate primary magma chambers. That hypothesis becomes almost, if not quite, incredible to any unprejudiced observer of the imposing likeness in the evolution of these distant, deep-sea island groups.

SUMMARY AND CONCLUSIONS

The writer's 1909 traverses in Hawaii have led to the view that the average of the many extant, typical analyses of its basalts approximates very closely the composition of the real average of all the basalt exposed in the island. This average is almost identical with that calculated for the world's average basalt. While Mauna Loa and Hualalai are basaltic from base to summit, Mauna Kea is, in a sense, stratified. Up to about the 6,000-foot contour, the broad basal slopes of Mauna Kea are underlain by the normal olivine basalt. From that contour to the summit platform, about 6,000 feet higher, the dominant lava is a basalt, very poor in olivine and, in other respects also, approaching the composition of a basic augite andesite. At the top of the mountain are flows and cinder-cones largely consisting of a still less femic type, in which alkaline feldspar (orthoclase or soda-

[1] W. W. Watts, *Geological Magazine*, XXIII (1896), 358.

orthoclase) seems often to form an essential constituent. This type is best classed as a trachydolerite of basaltic affinities. Its chemical analysis is almost identical with that of a common phase of the andesitic basalt, but, for some reason, alkaline feldspar did not crystallize from the latter magma. This arrangement of rock-species in Mauna Kea is explained as due to gravitative differentiation in the normal basaltic magma.

More pronounced splitting is registered in the highly alkaline trachydolerites and phonolitic trachyte occurring in the Kohala district and at Puu Anahulu and the neighboring Puu Waawaa. The development of these extreme types is tentatively ascribed to changes in the normal basalt by its solution of small quantities of sedimentary limestone cut by the respective lava conduits. No direct evidence for this hypothesis has been found; it is based on facts derived from the field and chemical relations of alkaline rocks throughout the world. Whether this hypothesis is correct or not, there can be little doubt that the alkaline rocks of Hawaii, Savaii, and other islands are as truly connected in a genetic way with the normal basalt, as ordinary aplite dikes are genetically connected with their respective granite batholiths. Such an origin for the Hawaiian alkaline rocks is rendered all the more probable because of their small relative bulk, and because of the perfect chemical transition which can now be shown between the normal basalt and the most salic of the alkaline types.

Further, a study of the olivine-pyroxene-anorthite segregations in the andesitic basalt and in the trachydolerite of Mauna Kea actually illustrates a stage of the differentiation. These nodules formed in the magma when its viscosity must have been enormous; else they would have rushed down into the conduit to levels where no summit eruption, of the small size represented in the flows and cones at the top of Mauna Kea, could have brought the nodules up again. It is almost certain that the settling-out of the olivine and pyroxene material (in solid or liquid phases) must have taken place at slightly higher temperatures, when the viscosity was much less. The residual magma must obviously become more alkaline in proportion to the degree of settling-out.

The ultra-femic material, sinking to great depth, where it

mixes with the hot, normal basalt, is subject to extrusion through lateral fissures which bring the deeper levels of the conduit into communication with the surface. Such is the preferred explanation for the ultra-femic olivine-basalt which emanated from Mauna Loa in 1852, and for the wehrlitic porphyry composing the Uwekahuna laccolith.

An explanation is offered for the apparently contradictory fact that gravitative differentiation is little evident in the thoroughly basaltic summit rocks of Mauna Loa and Hulalai, or in the material of the active vent at Kilauea.

As a result of studies in this and other fields, and in the general literature of petrology, the writer is inclined to the belief that all late pre-Cambrian and younger "alkaline" rocks are the result of differentiation within primary basaltic magma or within syntectic magmas formed by the solution of solid, generally sedimentary, rock in the primary basalt. The marvelously uniform composition of the basaltic magma issuing from countless fissures in every ocean basin as in every continental plateau, seems capable of explanation only on the premise that it forms the material of a continuous, world-circling substratum. The facts of geology suggest that this substratum was formed by an ancient liquation which took place when the globe was molten at its surface. This general conception became gradually clear to the writer during the genetic study of many intrusive bodies; it had been visualized in much the same form by that extraordinarily suggestive observer of the Hawaiian volcanoes, W. L. Green, whose *Vestiges of the Molten Globe*, Part II, first became known to the present writer in 1909. Not a single one of the myriad facts recorded in general petrography and geology definitely opposes this hypothesis, which, to the writer, seems to be the best working premise for a general philosophy of the igneous rocks.

Lastly, it appears from the accumulating results of geological work that the division of igneous rocks into "Atlantic" and "Pacific" races or groups is not warranted by the facts of distribution, nor by the requirements of sound petrogenic theory, nor by the needs of systematic petrography. In the heart of the Pacific basin, as in many regions along its borders, rocks of foyaitic,

theralitic, or other alkaline habit are already known, and the number of occurrences in that part of the earth is constantly growing. It may be quite true that alkaline rocks are more abundant on the Atlantic side of the globe—possibly because thick prisms of calcareous sediments are, in proportion to area, more developed in the Atlantic region—but it is yet more apparent that the overwhelming mass of the igneous rocks in the Atlantic region are subalkaline in type. The distinction of the two "Atlantic and Pacific races" (Sippen) is not only fallacious in the literal, geographic sense; it introduces an unnecessary pair of terms of quite elusive definition in place of the well-established, less nebulous terms "alkaline" and "subalkaline." The proved difficulty of making a clean-cut definition of the expression "alkaline rock" finds explanation in the theory that all late pre-Cambrian and younger alkaline rocks are of secondary origin, because derived from basalt or from its syntectics. According to this view, many transitional types should be found between the highly alkaline species and those low in alkalies; iron-clad definition becomes impossible.

PETROGRAPHIC TERMS FOR FIELD USE

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Velut aegri somnia, vanae
Finguntur species, ut nec pes nec caput uni
Reddatur formae.

—Horace, *De arte poetica*, 7.

Horace wrote this stanza with no idea of how aptly it would apply to the megascopic classifications of rocks in use at the beginning of the twentieth century. When the estimable authors of the Quantitative System appended a field classification to their system, they recognized the impossibility of accurately determining rocks megascopically, and said:

It is obvious that a considerable part of the system of classification and nomenclature here proposed can only be applied upon microscopical or chemical investigation. . . . . For these reasons . . . . we are convinced of the need of general petrographical terms, which will be serviceable in the field work of the petrologist, and which will be of use to the general geologist and to those who may not be able to carry on microscopical and chemical investigations.

The authors proposed to select, from the terms originally given by the geologists of the past, certain rock names and to give to them their original significance "so far as possible, with only such modifications as a somewhat more systematic treatment of the matter may suggest." The suggestion was truly commendable, for the need of a field classification was seriously felt. Unfortunately, perhaps, we are not living in the old days. The former rock terms have, in the course of time, acquired new meanings, and an attempt to revive the old ones produces much confusion.

Ut sylvae foliis pronos mutantur in annos,
Prima cadunt; ita verborum vetus interit aetas,
Et juvenum ritu florent modo nata vigentque.

—Horace, *op. cit.*, 60.

And so it is with the old petrographic terms.

So far as the grouping of the rocks proposed by C. I. P. W. is concerned, it is most admirable, and can hardly be improved upon; it is only upon the rock terms chosen by them that any criticism falls. Teaching the names as selected, it is necessary to impress upon the student that these are only indefinite field terms—and he immediately wants to know the more exact definitions. The student who later takes up microscopical work finds—at the present time when the older systems must still be taught, even if supplementary to the newer—that these definitions produce confusion, and he must either "unlearn" the field terms or else originally he must have learned the more exact usage as well. The objection to the latter method is that it makes double work for those students who want only a general megascopic knowledge of the rocks. Had some simple change been made by the authors of the Quantitative System, either in the words used or in their endings, this difficulty would have been overcome. The following substitutes are proposed as expressing, more or less, the fact that the general type of rock represented by the original name is the one preponderating in the group, and for this reason the suffix *-eid* (from εἶδος, "form, appearance") was chosen. As a matter of fact the change proposed is not so great as the spelling would suggest. It is only a change in the *pronunciation* produced by the substitution of a single letter—from granite to granide, syenite to syenide, etc. The object in using *-eid* instead of *-ide* is twofold. It conforms to the derivation of the word, and in those countries where the final *e* is omitted, the ending *ide*, changed to *id*, has the short sound; *-eid* is everywhere pronounced the same. It will be noted that some of the C. I. P. W. terms are retained, for to such words as phanerite and aphanite there are no objections. For uniformity, however, the same ending is used below in these forms as in the others.

As divided by the authors of the Quantitative System, so here also the rocks are divided into three main divisions.

I. *Phanereids* (φανερος, "visible," and εἶδος, "form"). Rocks whose different constituents can be seen megascopically.

II. *Aphaneids* (αφανης, "unseen," and εἶδος). Rocks which contain a greater or lesser amount of megascopically indeterminable components. These are subdivided into

a) *Aphaneids*, properly so called. Non-porphyritic.

b) *Aphaneid porphyries.* Porphyritic rocks with aphanitic groundmasses. For consistency some other word should be substituted for porphyry, since this term is generally applied only to orthoclase rocks, and by some writers to rocks with two generations of minerals, with or without phenocrysts. The term, however, is in such general use among miners and quarrymen, and by the U.S. Geological Survey, for all rocks containing larger crystals in a fine-grained or dense ground-mass, that it may be better to retain it. Poikileid (ποικιλος, "spotted," and εἶδος) would be much better.

III. *Glasses.* Rocks which are hyaline or which have hyaline ground-masses.

On the basis of mineral composition, the rocks can be divided megascopically most easily into those that are light and those that are dark. Consequently the groups are divided into those in which

1. Femag[1] minerals form less than half the rock.
2. Femag minerals form over half the rock.
3. Light-colored minerals absent or nearly so.

While it is generally impossible to separate different feldspars megascopically, quartz can usually be recognized. Its presence or absence is therefore made the basis of a further subdivision, as is also the presence or absence of olivine in the no-feldspar rocks.

It has been found possible to subdivide the rocks megascopically into the following groups:

I. PHANEREIDS

Graneid.—A holocrystalline, medium- to coarse-grained igneous rock, consisting of quartz and any kind of feldspar, with one or more members of the biopyribole group,[2] generally biotite or hornblende. The femag minerals form less than 50 per cent of

[1] The term *femic* has been used repeatedly by recent writers as synonymous with ferro-magnesian. This is incorrect, since femic minerals include apatite, fluorite, calcite, etc. The term *femag* is here used for ferro-magnesian.

[2] *Biopyribole* is suggested as a substitute for the awkward words biotite $\left\{ \begin{matrix} \text{and} \\ \text{or} \end{matrix} \right\}$ pyroxene $\left\{ \begin{matrix} \text{and} \\ \text{or} \end{matrix} \right\}$ amphibole, and *pyribole* for pyroxene $\left\{ \begin{matrix} \text{and} \\ \text{or} \end{matrix} \right\}$ amphibole.

the rock. Under this term are included all granites, and the light-colored quartz diorites.

Syeneid.—A holocrystalline, medium- to coarse-grained igneous rock, consisting of one or more kinds of feldspar and one or more members of the biopyribole group, generally biotite or hornblende. The femag minerals form less than 50 per cent of the rock. Under this term are included syenites, nephelite syenites, and the light-colored diorites.

There is a slight objection to this term in that the pronunciation is the same as cyanide. Sinai-eid (the rock at Sinai being a true syenite) might be used except for the superabundance of vowels. Esseneid or Assuaneid, from the modern names for Syene, are also suggested, but on the whole, on account of the common use of the term syenite, it seems best to retain syeneid.

Dioreid.—A holocrystalline, medium- to coarse-grained igneous rock in which the femag mineral is an amphibole and forms over half the constituents. Feldspar, of any kind, is subordinate in amount. To this group belong the shonkinites, the dark-colored diorites, and the hornblende gabbros.

Quartz dioreid is a subgroup.

Gabbreid.—A holocrystalline, medium- to coarse-grained igneous rock in which the femag mineral is pyroxene and forms over 50 per cent. Feldspar, of any kind, is subordinate in amount. Here are included the augite diorites, gabbros, and norites.

Quartz gabbreid is a subgroup.

Dolereid.—It is usually impossible to determine, megascopically, the species of pyribole present. In such cases the term dolereid may be used instead of dioreid or gabbreid.

Quartz dolereid is a subgroup.

Pyroxeneid.—A holocrystalline, medium- to coarse-grained igneous rock which consists almost entirely of pyroxene. The term covers the rocks now called pyroxenites.

Amphiboleid.—A holocrystalline, medium- to coarse-grained igneous rock which consists almost entirely of amphibole. It includes igneous hornblende rocks, whether the hornblende is primary or secondary.

Pyriboleid.—A holocrystalline, medium- to coarse-grained ig-

neous rock, consisting almost entirely of one or more members of the pyribole group. It includes the pyroxeneids and amphiboleids, and corresponds to dolereid among the feldspar rocks.

Peridoteid.—A holocrystalline, medium- to coarse-grained igneous rock, consisting of olivine, with or without pyriboles. Feldspar is absent. This group includes the peridotites.

II. APHANEIDS

Felseid.—An aphanitic igneous rock, non-porphyritic and light-colored. Here are included non-porphyritic rhyolites, trachytes, phonolites, latites, and the light-colored andesites. They are *leuco-aphaneids* (λευκος, "white").

Felseid porphyry.—Under this head are grouped all light-colored porphyritic igneous rocks with aphanitic ground-masses. They may also be called *leucophyreids.*

Quartz felseid porphyries or quartz leucophyreids are those felseid porphyries among whose phenocrysts quartz can be recognized. Other mineral modifiers, such as orthoclase, biotite, hornblende, etc., may be used for different varieties.

Anameseid.—An aphanitic igneous rock, non-porphyritic and dark colored, generally dark gray, dark green, dark brown, or black. In this group are included the dark andesites and basalts. They are *melano-aphaneids* (μελανος, "dark").

No sharp line can be drawn between these rocks and the felseids. The relative amounts of the dark and the light constituents cannot be determined megascopically, and it is only possible to classify the felseids by their colors, which are white, yellow, light brown, pink, and pale gray.

Basalt, being such an overworked word, von Leonhard's term anamesite was chosen instead as the root. It was originally applied to basaltic rocks of such fine texture that the constituents were indistinguishable megascopically.

Anameseid porphyry.—In this group belong all dark-colored porphyritic igneous rocks with aphanitic ground-masses. The term *melanophyreid* may also be used. If the phenocrysts can be determined, their names may be prefixed, as biotite melanophyreid or biotite anameseid porphyry, etc.

III. GLASSES

Since the glasses can be determined megascopically as such, the usual terms are retained, as pumice, obsidian, pitchstone, etc. For the porphyritic glasses the term *vitrophyreids* is proposed.

Tabulating these terms:

	Femag Minerals <50 per cent		Femag Minerals >50 per cent		No Feldspar or Quartz	
	+Quartz	−Quartz	− Quartz	−Quartz	−Olivine	+Olivine
Usual femag	Biotite	Biotite, Amphibole	Amphibole	Pyroxene	Pyribole	Olivine, Pyribole
Glasses	Pumice, obsidian, pitchstone, etc.					
Porphyritic glasses	Vitrophyreids					
Aphaneids	Felseid		Anameseid			
Aphaneid porphyries	Felseid-porphyry or leucophyreid		Anameseid porphyry or melanophyreid			
Phanereids	Graneid	Syeneid	Dioreid	Gabbreid	Amphiboleid Pyroxeneid	Peridoteid
			Dolereid		Pyriboleid	

Such a classification can be learned by a student in ten minutes. The rocks are subdivided into as many groups as can be recognized megascopically, and unknown specimens classified by different persons will almost invariably be found to fall into the same groups. Frankly acknowledging, by the names used, the field character of the determinations, there will be no confusion caused if later more exact terms are applied to the same rocks.

THE EVOLUTION OF LIMESTONE AND DOLOMITE. I

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CONTENTS

INTRODUCTION

Many writers[1] have called attention to the decrease in the percentage of dolomite in going up the geologic time scale, and

[1] Daly has shown the decrease in dolomite with age in the following compilation of analyses (Table I, from *Bull. Geol. Soc. Am.*, XX, 165):

TABLE I

AVERAGE RATIO OF CALCIUM TO MAGNESIUM IN LIMESTONES OF DIFFERENT PERIODS

Period	1 Number of Analyses	2 Ratio of $CaCO_3$ to $MgCO_3$	3 Ratio of Ca to Mg
Pre-Cambrian:			
a) From North America, except those in *b*)	28	1.64:1	2.30:1
b) From Ontario (Miller)	33	4.92:1	6.89:1
c) Average of *a*) and *b*)	61	2:93:1	4.10:1
d) Best general average	49	2.58:1	3.61:1
Cambrian (including 17 of the Shenandoah limestone)	30	2.96:1	4.14:1
Ordovician	93	2.72:1	3.81:1
Silurian	208	2.09:1	2.93:1
All pre-Devonian	392	2.39:1	3.35:1
Devonian	106	4.49:1	6.29:1
Carboniferous	238	8.89:1	12.45:1
Cretaceous	77	40.23:1	56.32:1
Tertiary	26	37.92:1	53.09:1
Quaternary and Recent	26	25.00:1	35.00:1
Total	865		

various hypotheses have been offered for its explanation. Probably the majority of geologists hold that it is due to a secondary alteration of limestone to dolomite, which is roughly proportional to time. Daly[1] has suggested that it is due to a change in the nature of the life processes which effect the precipitation of carbonates in the sea. Still another alternative hypothesis is herewith offered, that the percentage of dolomite developed in the sea has declined with time, and that this was controlled by a progressive increase in the ratio of calcium to magnesium contributed from the lands.

Absolute proof for any one of these hypotheses is impossible from the very nature of the problem. For instance, all of them are based on the theory of uniformitarianism, a theory deep rooted in geologic evidence, but a theory nevertheless. All the hypotheses offered involve the question of whether dolomite develops predominantly in the sea, regardless of the specific processes of formation, or whether it is predominantly a secondary product from limestones, after their emergence from the sea. If its origin is mainly in the sea, which of the factors controlling deposition in the sea has changed so as to cause a decline in its deposition with time? Was it temperature, pressure, life processes, the chemical composition of the sea, or some combination of these factors? To these no final answer can be made. The available evidence for each view can be sifted. Conclusions may be drawn, but the probability may be freely recognized that in the future some of the conclusions may become invalidated.

PART I. THE EVIDENCE ON THE ORIGIN OF DOLOMITE

That the predominance of dolomite in the ancient sediments is due in a larger measure to primary conditions of deposition in the sea than to the metamorphism of limestones after their emergence from the sea seems to follow from a comparison of the evidence on the origin of dolomite in the sea with that on the origin of dolomite by the metamorphism of limestone after its emergence from the sea.

A. THE EVIDENCE FOR THE ORIGIN OF DOLOMITE IN THE SEA

Interstratification of limestones, magnesian limestones, and dolomites the result of primary conditions of sedimentation, or of the

[1] *Ibid.*

differential metamorphism of limestones after their emergence from the sea.—In a succession of conformable formations, each formation usually presents a certain specific lithologic unity of character which is different from that of adjacent formations, and may or may not be related to them by gradation phases. Thus limestones are not infrequently sharply interstratified with dolomites, and give by their color contrasts a graphic portrayal of the sharp lithologic difference which frequently distinguishes adjacent carbonate formations. Attention is directed to a number of typical illustrations of sharply defined stratigraphic cleavage between limestones and dolomites. The "lead and zinc" district of southwestern Wisconsin presents the following interesting succession:

System	Formation	Average Thickness in Feet	Lithological Character, etc.
Ordovician	Hudson River	160	Shale.
	Galena	250	Dolomite. Limestone layers, sharply interstratified near bottom.
	Containing oil rock	3±	Oily shale, not deposited everywhere.
	Clay	3±	Not deposited everywhere.
	Glassrock	3±	Sharply defined limestone. Very pure.
	Platteville	55	Magnesian limestone and dolomite.

A striking case of sharp interstratification of nearly pure limestone beds and dolomites is described by F. B. Peck[1] as occurring in the Trenton of Lehigh and Northhampton counties, Pa.

I. P. Lesley's[2] study of the Cambro-Silurian limestones of Cumberland County, Pennsylvania, is perhaps the most detailed quantitative chemical study of a limestone section which has ever been made from the viewpoint of throwing light on the origin of limestone and dolomite. The section studied was about 375 feet

[1] F. B. Peck, *Eco. Geol.*, III, No. 1, p. 43.

[2] I. P. Lesley, *Second Geol. Survey Pa.*, Vol. MM (1897), pp. 311–62.

thick, consisting of conformable, uniformly dense, slightly disturbed beds of limestone sharply interstratified with beds of magnesian limestone and dolomite. Analyses taken from various parts of each bed showed that each bed constituted a lithologic unit which often differed sharply from adjacent beds.

To E. Suess,[1] the sharply defined, thin-bedded intercalations of limestone and dolomite in the Plattenkalk present such powerful evidence of characters which could not have been acquired by metamorphism after their emergence from the sea, that he regards them as direct chemical precipitates. While it may be difficult to agree with Suess that chemical precipitation, in cases like that of the Plattenkalk, is proven, there certainly can be no doubt that it is easier to conceive of such formations as being the direct result of sedimentary processes in the sea, than to believe them to be the result of the differential metamorphism of limestone beds after their emergence from the sea. It is difficult to see how the metamorphism of a succession of conformable limestone beds or formations after their emergence from the sea could be so thoroughly selective as to result in a succession of beds or formations of unlike composition. Circulating underground water, the most universal agent of the alternation of sediments after their emergence from the sea, is obviously most effective along joints, bedding planes, or other large openings both parallel to and across the bedding, the so-called "trunk channels of circulation" repeatedly emphasized by Van Hise in his "Treatise on Metamorphism."

Until more direct evidence has been submitted for the origin of dolomite formations through circulating underground water, it seems more reasonable to assume that interstratifications of dolomite and limestone result from primary conditions of sedimentation, regardless of what the specific processes of limestone and dolomite building may have been.

Fineness of grain, peculiar to some dolomites, probably indicative of very little metamorphism since deposition.—Attention is directed to the fineness of grain which some dolomites possess. Daly[2]

[1] E. Suess, *The Face of the Earth*, II, 262.

[2] R. A. Daly, "The Evolution of the Limestones," *Bull. Geol. Soc. of America*, XX (1909), 167–68.

finds that the slightly disturbed dolomites of Cambrian and pre-Cambrian age of the forty-ninth parallel section of the Rocky Mountain geosynclinal, aggregating about 7,000 feet in thickness, are singularly monotonous in their fineness of grain, averaging about 0.02 millimeter. Other fine-grained and similarly undisturbed dolomites mentioned by Daly are those of the Archean at the headwaters of the Priest River, Idaho, the magnesian limestones and dolomites inclosing the chitinous fossil Beltina donai in the Clarke range and the Siyeh and Sheppard siliceous limestones of northwestern Montana, probably of middle Cambrian age. He also quotes Vogt as stating that the finest grained Norwegian dolomites average from 0.02 to 0.03 millimeter in diameter.

Willis and Blackwelder in their studies of the geology of China for the Carnegie Institution describe a number of very fine-grained, dense dolomites of considerable extent and thickness.

The pre-Cambrian dolomite formation of the Baraboo[1] synclinal is singularly fine grained. The Niagara limestone of Wisconsin, a dolomitic formation, is generally a very even-textured, fine-grained, and compact rock.

The generalization may be deduced from the facts cited that many undisturbed or only slightly disturbed dolomites are exceedingly fine grained and compact. There does not appear to be any evidence that this fineness of grain is the result of granulation. Furthermore, the relative mobility and regenerative power of the carbonates is very great as compared with the other minerals. Coarse-grained, even-textured[2] marbles showing no strain effects are found interbedded with banded gneisses with marked strain effects. Unless conditions are peculiarly unfavorable for recrystallization, the metamorphism of dolomites would probably result in coarser grain. The fineness of grain and compactness of many dolomites may therefore be interpreted as showing that they were dolomite before they emerged from the sea.

Many dolomite formations lack fossils.—The opinion is reflected from geologic literature that fossils are less common in dolomite

[1] S. Weidman, "Baraboo Iron-bearing District," *Wisconsin Survey Bull.*, No. 13 (1904), p. 67.

[2] C. R. Van Hise, "Treatise on Metamorphism," *U.S.G.S. Mon. 47*, p. 738.

than in limestone, although no quantitative study of this problem seems to have been made. It has been observed in various places that the limestone beds intercalated between dolomite are full of fossils, while the dolomite is barren. Illustrations of this are found in the Galena limestone of Wisconsin. The paucity of fossils in dolomites has been variously interpreted, some holding that fossils were never present in the formation because the conditions at the time of deposition were unfavorable to life, while others claim that they were originally present but have been destroyed by metamorphism. In connection with the first interpretation, it is interesting to note that magnesium-bearing solutions have actually been found to be unfavorable to life processes. It may be the correct interpretation in the case of certain dense, fine-grained dolomites. On the other hand, porous, cavernous dolomites like the Lower Magnesian of the Upper Mississippi valley, which is nearly devoid of fossils, evidently has undergone considerable recrystallization which may have destroyed the fossil record. No final conclusion seems to follow from the apparent fossil barrenness of dolomites with reference to the origin of dolomite.

Association of certain dolomites with gypsum and salt deposits.—Of certain dolomites which are found with deposits of salt, gypsum, and red beds and other indications of aridity and concentrated seas, it has been suggested that they are direct chemical precipitates, since conditions of deposition were apparently unfavorable to life. This view is open to the criticism that no case is known where this process is in operation at the present time. However, regardless of what the specific processes of dolomite building were, it seems more likely that these deposits were primarily dolomite because gypsum tends to decompose dolomite into calcium carbonate and magnesium sulphate. Therefore, if any alteration of the deposit had taken place since deposition, it would seem more likely to result in the decomposition of dolomite than in dolomitization.

Chemical precipitation of dolomite in the sea.—Crystals of dolomite grow in vugs and cavernous openings of coral reefs in the Pacific Ocean, according to E. W. Skeats.[1]

[1] E. W. Skeats, *Bull. Mus. Comp. Zoöl.*, XLII (1903), 53–126.

Experimental evidence for the chemical precipitation of dolomite.—The direct precipitation of dolomite from solution has apparently not been done, experimentally. Sterry Hunt[1] precipitated calcium carbonate and the hydrous carbonate of magnesium with sodium carbonate and found that he could develop dolomite by heating this mixture to 120° C.–130° C. Obviously this experiment did not accomplish direct chemical precipitation of dolomite nor is it applicable to the explanation of the majority of dolomites in nature.

Daly's hypothesis of the direct precipitation of dolomite in the primitive ocean.—Daly[2] postulates that dolomite was precipitated from a nearly limeless primitive ocean by ammonium carbonate generated by the decay of organisms on the bottom of the ocean. The hypothesis is based on several assumptions, namely: (*a*) the scavenging system of the pre-Cambrian and the early Paleozoic ocean was less perfect than at present; (*b*) the post-Huronian uplift gave a tremendous impetus to the transportation of lime to the sea, which in turn stimulated the development of lime-secreting organisms; (*c*) the improvement of the scavenging system and the development of lime-secreting organisms gradually brought the balance in favor of the deposition of limestones by organic secretions over direct chemical precipitation. The theory is offered to explain a number of facts: (*a*) the predominance of dolomite in the older formations; (*b*) characteristics such as grain, fossil record, and field relations of certain dolomites indicative of direct chemical precipitation; and (*c*) the apparent similarity between the ratio of calcium to magnesium in the older dolomites and the ratio of calcium to magnesium of streams on pre-Cambrian crystalline terranes. This theory fits many facts remarkably well. However, the premises on which it is based are open to objection.

It is true that the decay of marine organisms generates[3] ammonium carbonate and other precipitants. But organic decay also generates carbonic acid, which tends to keep the carbonates of

[1] Sterry Hunt, *Chem. and Geol. Essays* (1895), 80.

[2] R. A. Daly, "First Calcareous Fossils and the Evolution of the Limestones," *Bull. Geol. Soc. of America*, XX, 153–70.

[3] G. Steinmann, *Ber. Naturforsch. Gesell. Freiburg*, IV (1889), 288; Challenger, *Report on Deep Seas*, 255.

lime and magnesia in solution. The rapid corrosion of marine shells is partly ascribed to this agency, by the authors of the Challenger deep-sea report. Thomson's[1] observations that the local abundance of carbonic acid on the ocean bottom is associated with an abundance of organisms is suggestive. Corrosion of calcareous remains by the direct action of sea water, but predominantly by the action of carbonic acid resulting from organic decay, is regarded by Murray as sufficiently powerful to prevent the accumulation of calcareous ooze at a mean depth of 2,730 fathoms, over 51,500,000 square miles of ocean bottom, the Red Clay area.

It therefore seems to be an open question whether the net chemical effect resulting from organic decay in the ocean is precipitation or corrosion. The scavengers of the present ocean do not arrest the accumulation of calcareous oozes over millions of square miles of the ocean bottom. The evidence that direct precipitation of calcium carbonate is taking place on those vast areas of organic decay is doubtful. Philippi,[2] viewing direct chemical precipitation as an important process in the origin of limestones, after citing the data offered by various investigators for direct chemical precipitation from the present ocean, concludes that certain incrustations and the cements of some oozes are probably chemical precipitates. He believes that warm seas, teeming with life, where decay on the bottom is rapid are favorable localities for the precipitation of calcium carbonate.

The acquisition of the lime-secreting habit by marine organisms in response to an accumulation of lime in the ocean postulated as a result of the post-Huronian erosion cycle, and the increase in scavengers may be possible. Paleontologists believe that at least nine-tenths of the organic evolution into main stocks was accomplished before the Cambrian. The Cambrian record contains evidence for the existence of all phyla excepting the vertebrates, and the unsuccessful search for vertebrate fossils in the Cambrian cannot be regarded as conclusive evidence for their absence. The burden of proof, therefore, rests heavily on any theory based on

[1] C. Wyville Thomson, *Depths of the Sea*, 502–11.

[2] Philippi, *Neues Jahrb.* (1907), 444.

radical differences in the organic development of the early Paleozoic, as compared with the present, and a correlative, fundamental difference in the constitution of the ocean.

Nor would all students of the pre-Cambrian admit that the profound importance which Daly attaches to the post-Huronian erosion cycle is evident. It was preceded by at least three periods of emergence in the Lake Superior and Lake Huron regions and in Finland. So far as known, any one of them may have contributed as much lime to the sea as the post-Huronian.

Deposition of magnesian limestones by marine organisms.—Marine organisms deposit magnesium carbonates in small quantities. According to G. Forchhammer,[1] marine shells and corals contain magnesium carbonate in varying amounts from 0.15 to 7.64 per cent, 1 per cent being rather above the average. In *Lithothamnium nodosum*, Gümbel[2] found 2.66 per cent of magnesium and 47.14 per cent lime, and Högbom[3] in fourteen analyses of algae belonging to this genus reports from 1.95 to 13.19 per cent of magnesium carbonate.

The development of magnesium limestones and dolomites by marine leaching.—It has been shown that marine leaching is very effective in concentrating the magnesian content of limestone formations. This is due to the fact that calcium carbonate is several times as soluble as magnesium carbonate, as was first shown by Bischoff. The decrease in calcium carbonate and the corresponding increase in magnesium carbonate resulting from marine leaching is well shown in the table on p. 333, compiled by G. Högbom.[4]

Högbom[5] washed the clay marl of Upsula with carbonated water with the following results. The original composition of the marl was calcium carbonate, 18 per cent, magnesium carbonate, 1.3 per cent. The loss of calcium carbonate was about 50 per cent, while the loss of magnesium carbonate amounted to only a trace.

In his studies of the marine marls of Sweden, Högbom found

[1] G. Forchhammer, *Neues Jahrb.* (1852), 854.

[2] Quoted from *Bull. 330, U.S.G.S.*, 485.

[3] Högbom, *Neues Jahrb.* I (1894), 262.

[4] *Ibid.*, 262–74.

[5] *Ibid.*, 268.

that the transported material contained progressively larger proportions of magnesium as its distance from the parent limestone increased. Near its point of origin, the marl carried 3.7 parts of magnesium carbonate to 100 of calcium carbonate, and from these figures the ratio was generally raised to 36 magnesium carbonate and 100 calcium carbonate.

TABLE II

TABLE COMPUTED FROM 21 GLOBERGERINA, 21 RED MUDS, 7 RADIOLARIAN OOZES, PTEROPOD OOZE, DIATOM OOZE, AND BLUE MUD

$CaCO_3$ Limits	$CaCO_3$	$MgCO_3$	Relative Values*	Analysis
80–100	86.7	17	.8	8
60–80	68.3	1.4	2.0	8
40–60	52.	1.2	2.4	8
20–40	32.	.9	3.0	3
10–20	16.2	1.6	10.0	4
5–10	6.1	.7	11.5	1
3–5	3.7	1.6	43.0	7
1–3	2.0	2.1	105.0	9

* Relative values express parts of $MgCO_3$:100 parts of $CaCO_3$.

The stalactites from the caverns in the coral rocks of Bermuda, according to Högbom, contain only 0.18 to 0.68 per cent of magnesium carbonate, while the rocks themselves carry about five times as much magnesium carbonate. The lime salt has evidently dissolved much more freely than the magnesium compound. This mode of concentrating magnesium carbonate must, from the evidence cited, be regarded as real, and may be instrumental in causing the development of dolomite. It is obvious that the smaller the content of calcium in the sea, as compared with magnesium, that is, the smaller the relative quantity of calcium resulting from the difference between contribution from the land on the one hand, and precipitation on the other, the more effective will be the process of leaching. The precipitation of calcium carbonate in the sea is now largely controlled by life processes, and probably has been at least as far back as the beginning of the Paleozoic, so that since Zoic times there has been a powerful agency at work, tending to deplete the calcium content of the sea, while leaving the soluble magnesium salts to accumulate. Solid phases of calcium carbonate are therefore farther removed from a condition

of equilibrium with sea water than the corresponding magnesium salt. Aside, then, from the inherent difference between the solubility of calcium carbonate and magnesium carbonate, the chemistry of the sea apparently facilitates the solution of calcium carbonate and retards that of magnesium carbonate. Assuming that the efficiency of the organic precipitation of calcium carbonate has been about the same throughout Zoic times, it seems obvious that the concentration of magnesium carbonate in calcareous deposits by marine leaching would have been even more effective than now, if at some time in the past the rivers had contributed relatively less lime and more magnesia than at present. If there is any probability that such has actually been the case, that would constitute one factor which would operate to cause an increase in the magnesium content of limestone in descending the geologic time scale.

The origin of dolomite by the secondary replacement of calcium by magnesium in the sea.—Coral rocks originally contain only a small percentage of magnesium carbonate, usually less than 1 per cent. In 1843, J. D. Dana[1] in a rock from the coral island of Makatea, in the Pacific, reported magnesium carbonate to the extent of 38.07 per cent. This approached the dolomite ratio which requires 45.7 per cent, and it was suggested that the rock had been dolomitized through secondary replacement, the magnesium carbonate probably having been derived from the concentration of shallow lagoons of sea water. Since Dana's time, many other investigators have recorded similar enrichments of coral reefs. In a coral reef from Porta do Mangue, Brazil, T. C. Branner[2] reports 6.95 per cent of magnesia, equivalent to 14.6 of carbonate, while the corals themselves contained only 0.20 to 0.99 per cent of magnesia. E. W. Skeats[3] reports analyses of dolomitic coral rock of the Pacific in which the magnesium carbonate rises to a maximum of 43.3 per cent.

The borings from the atoll of Funafuti as discussed by J. W. Judd[4] present a remarkable case of transformation from reef

[1] J. D. Dana, *Corals and Coral Islands* (3d ed.), 393.

[2] T. C. Branner, *Bull. Mus. Comp. Zoöl.*, XLIV (1904), 264.

[3] E. W. Skeats, *Bull. Mus. Comp. Zoöl.*, XLII (1902), 53–126.

[4] J. W. Judd, *The Atoll of Funafuti*, quoted from *Bull. 330, U.S.G.S.*, 487.

rock to dolomitic limestone. The principal boring was driven to a depth of 1,100 feet, through coral and coral rock all the way, and samples of the cores were analyzed every ten feet of the distance. The following table of data, quoted by *Bull. 330, U.S.G.S.*, p. 487, shows first, an enrichment in magnesium carbonate near the surface, then an irregular rising and falling in much smaller amounts, while below 700 feet the rock approaches the dolomite ratio.

TABLE III

Magnesium Carbonate in Borings on Atoll of Funafuti

Depth Feet	Percentage $MgCO_3$	Depth Feet	Percentage Magnesium Carbonate
4	4.23	295	3.6
13	7.62	400	3.1
15	16.40	500	2.7
20	11.99	598	1.06
26	16.0	640	26.33
55	5.85	698	40.04
110	2.11	795	38.92
159	0.79	898	39.99
200	2.70	1000	40.56
250	4.9	1114	41.05

In the analyses of coral rock borings from an artesian well at Key West, Florida, reported by George Steiger,[1] there is no apparent relation between the content of magnesia and depth as shown by the borings on the atoll of Funafuti.

TABLE IV

Lime and Magnesia in Borings at Key West

Depth Feet	Percentage CaO	Percentage MgO	Depth Feet	Percentage CaO	Percentage MgO
25	54.03	0.29	1325	54.49	0.62
100	54.01	0.77	1400	55.12	0.30
150	54.38	0.86	1475	54.48	0.73
350	51.46	1.67	1625	53.90	1.14
600	48.87	2.50	1850	54.28	1.12
775	46.53	6.70	2000	54.02	1.06
1125	53.84	0.86			

The dolomitization of organic calcareous deposits in the sea by secondary replacement as well as by leaching seems to be too well established to admit of serious doubt. The degree of dolo-

[1] George Steiger, *Bull. 228, U.S.G.S.* (1904), 309.

mitization in any given case may be influenced slightly by the original composition of the calcareous secretions: witness the difference in the content of magnesium carbonate in secretions from Lithothamnium and other members of this genus as compared with those of the corals. Certain calcareous secretions have been found to consist of calcite while others like those of the corals consist largely of aragonite. Aragonite is much less stable than calcite, hence the aragonite secretions are probably much more subject to dolomitization through leaching and replacement than the more stable form of calcium carbonate, calcite. Furthermore, it is highly probable that the composition of the sea is an important factor in dolomitization. If sea water is high in magnesium and low in calcium, it is probable that the conditions are more favorable for the dolomitization of calcareous deposits than if the reverse condition prevailed, as may be inferred from the following experiments. If a crystal of calcite is placed in water, solution will take place until equilibrium is reached between the calcite and the solution. Obviously, replacement, in the absence of magnesium salts, cannot take place. On the other hand, Sorby found that a crystal of calcite placed in a concentrated solution of magnesium chloride became slowly incrusted with magnesium carbonate, and Pfaff developed a dolomitic material by subjecting calcium carbonate to the action of a solution of magnesium chloride or sulphate and common salt, under pressure comparable to the deep sea, in which case the speed of reaction was proportional to the concentration of the solution.

It is obvious that 60 pounds of calcium carbonate could not be replaced by a solution containing only 10 pounds of magnesium salt in anything like the proportions required by the dolomite ratio. It seems equally probable, a priori, that if the river waters carried calcium and magnesium to the sea in the ratio of 1:1, the chances for dolomitization through leaching, secondary replacement, or possibly primary deposition would be better, all other things being equal, than when the proportion of river-borne calcium to magnesium is 6:1, which is the approximate ratio at the present time according to the best estimate.[1]

[1] See F. W. Clarke, "A Preliminary Study of Chemical Denudation," *Smithsonian Mis. Coll.*, LVI, No. 5, p. 8.

Experimental evidence on the origin of dolomite by secondary replacement of calcium chloride.—A summary of the principal experimental methods by which the dolomitization of calcium carbonate by replacement has been effected follows:

1. REPLACEMENT AT HIGH TEMPERATURE

By heating calcium carbonate and a solution of magnesium sulphate in a closed tube at 200° C. (Morlot, *Jahresb. Chemie* [1847–48], 1290).

By heating carbonate of lime to over 100° C. with a solution of magnesium bicarbonate (F. Hoppe-Seyler, *Zeitsch. Deutsch. Geol. Gesell.*, XXVII [1875], 509).

By the action of a solution of magnesium chloride on calcium carbonate at high temperature (Marignac and Faber, *Compt. Rend.*, XXVIII [1849], 364).

By saturating chalk with a solution of magnesium chloride and heating the mass on a sand bath (Saint-Claire Deville, *Compt. Rend.*, XLVII [1858], 91).

By heating fragments of porous limestone with dry magnesium chloride in a gun barrel (J. Durocher, *Compt. Rend.*, XXXIII [1851], 64).

It is probable that the preceding experiments on the replacement of calcium carbonate have very little significance in relation to the development of dolomite in the sea, since the continuity of the life record back as far as the pre-Cambrian, at least, precludes the possibility of a universally hot ocean. Very locally, as in the case of the eruption of Krakatao, the required temperatures may have been duplicated in the ocean. They are more likely to have been paralleled in some cases of contact, metamorphism of limestones generally following their emergence from the sea.

2. REPLACEMENT ABOVE 60° C.

By action of magnesium sulphate on aragonite in a concentrated solution of common salt at a temperature above 60° C. (Klement, *Min. Pet. Mitth.*, XIV [1894], 526).

The same objection holds against the application of this experi-

ment of the development of dolomite in the sea as was urged against the preceding group of experiments. The highest temperatures of the sea, resulting from solar heating, on record are those of the Red Sea[1] (31° C.), and the Lagoons of the Celebes (32° C.).

3. FORMATION OF DOLOMITE AT ORDINARY TEMPERATURE AND PRESSURE

By action of magnesium chloride and magnesium sulphate in water on anhydrite in the presence of common salt and carbonic acid (Pfaff, Jr., *ibid.*, 557).

By action of hydrogen sulphide in water on magnesium and calcium carbonates, followed by the introduction of carbonic acid (Pfaff, Jr., *ibid.*, 556).

4. FORMATION OF DOLOMITE AT ORDINARY TEMPERATURE AND HIGH PRESSURE

By the action of sodium carbonate on anhydrite in the presence of common salt in a concentrated solution of magnesium sulphate or chloride (Pfaff, *ibid.*, 562).

By the action of magnesium chloride or sulphate in a solution of common salt on calcium carbonate. The speed of the reaction is proportional to the degree of concentration of the solution (Pfaff, *ibid.*, 565).

Pfaff's experiments are highly creditable in that the replacement of calcium carbonate by a magnesium salt so as to yield a product approaching the dolomite ratio was effected without resort to high temperatures. Doubtless other methods will yet be worked out whereby this result can be obtained under conditions similar to those prevailing in the sea. The last experiment by Pfaff is highly suggestive when compared with the increase in the magnesium content of marine oozes with depth; that is with pressure (see this paper, p. 335). However, it does not seem safe to argue that this has been a very important factor of control, since many dolomites have very obvious earmarks of shallow-water deposition, such as ripple marks, cross-bedding, and interstratification with coarse sands.

[1] Quoted by F. W. Pfaff, *Neues Jahrb. Min. Beilage,* XXIII (1907), 573.

B. THE EVIDENCES FOR THE ORIGIN OF DOLOMITE BY THE METAMORPHISM OF LIMESTONES AFTER THEIR EMERGENCE FROM THE SEA

Direct chemical precipitation of dolomite.—The occurrence of dolomite in veins and vugs of limestone and dolomite is well known. So far as the recorded facts seem to indicate, direct chemical precipitation of dolomite in fissures and openings of carbonate formations, after emergence from the sea, seems to be much more important than the chemical precipitation of dolomite in the sea at the present time. However, dolomite as a cement and vein filler is quantitatively of far less consequence than calcite. Furthermore, it is not certain to what extent dolomite in veins merely means the transfer of previous existing dolomite originally developed in the sea. Direct chemical precipitation of dolomite in formations after their emergence from the sea, while probably more important than the chemical precipitation of dolomite in the sea at the present time, is nevertheless a very subordinate process and cannot be regarded as an important source of dolomite formations.

Origin of dolomite by leaching limestones after their emergence from the sea.—The dolomitization of limestones after their emergence through leaching is a very important process wherever both the calcium carbonate and dolomite are originally present, because of the differential solubility of the two carbonates. Unquestionably a unit volume of water as it enters the soil, but charged with atmospheric gases, is a much more efficacious solvent than an equal volume of sea water, but the total volume of sea water which is effective in leaching carbonates in the sea is vastly greater than the volume of water in the lithosphere. Leaching of limestones by underground waters probably changes the ratio of calcium to magnesium but little excepting near the surface, because the porosity, slumping, and faulting which would need to follow from converting a magnesian limestone containing even 13 per cent of magnesium carbonate into a dolomite through leaching is not at all evident in dolomite formations. Evidence is cited showing that weathering does increase the percentage of magnesia in limestones. Since effective leaching of limestones by ground water is related to weathering, it is improbable that

this process accounts for the stratigraphic separation of limestones, magnesian limestones, and dolomites, or for any large proportion of the dolomite in nature.

Origin of dolomite by secondary replacement of limestone.—Secondary dolomitization along fissures had been described by Prestwich,[1] Geikie,[2] Bain,[3] Pfaff,[4] Spurr,[5] and others. The alteration of limestones by hot, magnesian spring waters at Aspen, Colorado, described by Spurr is significant, but obviously, secondary replacement by underground water seems to be only local. A brief consideration of the chemistry of ground water and of the ocean is suggestive in showing the probabilities for the relative replacing power of sea water and underground water. Sea water[5] contains calcium and magnesium in the ratio of 1 to 3.11. The salinity is 3.301 to 3.737, of which 1.197 per cent is calcium and 3.725 per cent magnesium. The constitution of underground water is variable and depends upon the local composition of the rocks from which it is taken. Underground water of terrestrial origin is nearly free from mineral matter at the start but contains solvent gases from the atmosphere. Obviously, if a unit volume of unmineralized underground water comes into contact with a unit weight of carbonate rock, solution follows until equilibrium is attained between the solid and liquid phases which are in contact. If the temperature, pressure, and the volume of water remain unchanged nothing further results. It is this history of the source of the salts in terrestrial underground waters which is unfavorable to replacement.

In humid regions, underground waters are essentially carbonate waters in which the principal positive ion is calcium. The following analysis may be taken as illustrative:

[1] Prestwich, *Geology—Chemical, Physical and Stratigraphical* (Oxford, 1886), I, 133–44.

[2] Geikie, *Textbook of Geology* (3d ed.; MacMillan, London, 1893), 321.

[3] Bain, "Preliminary Report on the Lead and Zinc Deposits of the Ozark Regions," *Twenty-second Ann. Rept. U.S. Geol. Survey*, Part II (1901), 208–10.

[4] Pfaff, *op. cit.*, XXIII (1907), 529–80.

[5] Spurr, "Geology of the Aspen Mining Dist., Colorado," *Mon. U.S. Geol. Survey*, XXXI (1898), 210–91.

[5] Mean of 77 analyses of ocean water from many localities collected by the Challenger expedition. Quoted from *Bull. 330, U.S. Geol. Survey*, 94.

COMPOSITION OF EXCELSIOR SPRINGS, MISSOURI[1]

SALINITY 489 PARTS PER MILLION OF WATER, OR ABOUT 0.4 PER CENT

Ca	29.28
Mg	3.15
Co_3	55.92

Ratio of Ca to Mg 9.3:1

The calcium carbonate of the ocean bottom is in contact with a solution high in magnesium and low in calcium, largely derived from the lands and not from the ocean bottom. The calcium carbonate of the land areas is on the average, so far as humid climates are concerned, in contact with carbonated waters high in calcium and low in magnesium whose salts are derived from the decomposition of the rocks through which they circulate. In the light of experimental evidence, on the replacement of calcium carbonate by magnesium carbonate, where are the conditions more favorable for dolomitization by replacement, in the ocean or in the sea of underground water? Of course there are analyses of underground waters which show a high content of magnesium, which could possibly cause dolomitization, but these seem to be either exceptional or local.

C. EVOLUTION VERSUS THE METAMORPHISM OF LIMESTONES AFTER THEIR EMERGENCE FROM THE SEA AS EXPLANATION FOR THE INCREASE IN THE RATIO OF CALCIUM TO MAGNESIUM OF LIMESTONES AND DOLOMITES WITH GEOLOGIC TIME

Evidence has been presented for both the development of dolomite in the sea and its origin by the metamorphism of limestones after their emergence from the sea. Magnesian limestones can develop in the sea from a combination of organic and inorganic processes. The known inorganic processes are direct chemical precipitation, leaching, and secondary replacement. These may also be effected through the agency of underground water. Evidence has been presented to show that these processes are operative in the sea on a much larger and more uniform scale because of the chemical properties of the sea as compared with those of underground water. Underground waters derive their dissolved materials from the rocks through which they circulate, and generally

[1] From *Bull. 330, U.S. Geol. Survey,* 150.

are high in calcium and low in magnesium, whereas the sea derives its materials largely from the lands and not from the ocean bottom. Sea water is low in calcium and high in magnesium, and is therefore a more favorable as well as a more universal medium for effecting the dolomitization of the ocean bottom than is underground water for the dolomitization of the rocks through which it circulates. The direct evidence for the dolomitization of limestones by underground waters which has been presented shows only local dolomitization along fissures and other openings, principally in the belt of weathering or in localities permeated by waters of unique chemical compositions, such as hot magnesian springs. The occurrence of dolomites of vast thickness and extent and the interstratification of limestones and dolomites cannot therefore find a ready explanation in the mutative agency of underground waters. Excepting for certain local occurrences, dolomite formations seem to have developed in the sea, rather than by the metamorphism of limestones after their emergence from the sea. The evolution of dolomite and limestones through a decline in the deposition of dolomite with time, therefore, seems to have a high degree of probability. Consequently, the gradual alternation from the predominance of dolomite in the ancient sediments to the dominance of limestones of a high ratio of calcium to magnesium in more recent times has probably been due to gradual changes in the condition of deposition in the sea.

WHAT FACTORS CONTROLLING THE DEPOSITION OF CALCAREOUS MARINE DEPOSITS HAVE UNDERGONE A GRADUAL EVOLUTION RESULTING IN THE EVOLUTION OF THE LIMESTONES AND DOLOMITES?

Four factors directly control the composition of the materials precipitated on the ocean floor: namely, pressure, temperature, life processes, and the chemical composition of the sea. Which of these factors has undergone a progressive change, reflected in the evolution of limestone and dolomites? It is almost needless to consider whether the pressures on the ocean floor have undergone a progressive evolutionary change within geologic time. All the water-deposited sediments found on the continents appear to have

the character of deposits now forming in shallow or moderate depths. None are like the abysmal deposits of the present ocean, a forceful argument for the permanence of the continents and the oceans. Nor is there any probability that the temperature of the ocean has undergone a progressive change which would account for the evolution of limestones and dolomites. The continuity of the life record down to the base of the Cambrian precludes the possibility of any marked change in the temperature of the ocean throughout Zoic times. But even beyond the Cambrian this relative uniformity of temperature may have persisted for a period of time, as long or even longer than from the Cambrian to the present, for paleontologists believe that approximately nine-tenths of the evolution of life into main stocks was completed at the beginning of the Cambrian. All the phyla are represented in the Cambrian excepting the vertebrates, and the fact that no vertebrate fossils have been found in the Cambrian cannot be regarded as positive proof that even they did not exist at this remote period of earth history. On the other hand, more and more evidence is accumulating in favor of Chamberlin's philosophic conception that the temperature of the ocean and the climatic conditions of the continents have undergone oscillations in consequence of periodic, areal changes of the lands with respect to the sea; that periods of land expansion are characterized by zonal, diversified climates, tending toward world-wide aridity and refrigeration, while periods of maximum oceanic expansion are associated with climatic uniformity, moderation, and humidity. There is then no probability that the temperatures of the ocean have undergone an evolution consonant with the evolution of dolomite and limestone.

Could the evolution of living organisms have been the controlling factor in the evolution of limestones and dolomites?

It would be difficult to disprove that organic control was a factor in the problem. Organisms play a gigantic rôle in the distribution of lime at the present time, and have for ages past. Biologists, however, lend considerable support to the hypothesis that organic activities are adaptations to physical and chemical environment, rather than creators of environment. In the long run, they may cause profound changes in environment, but the

keynote of their activity is adaptation rather than control. The selection of potassa rather than soda by the land plants and the selection of soda in preference to potassa by marine plants has been cited as evidence for the adaptation of life processes to chemical environment. The preference of lime-secreting organisms for calcium rather than for magnesium may be a similar adaptation. It is suggestive that calcium carbonate is the principal salt contributed to the sea, and that in localities most favorable to life, lime carbonate is the most insoluble of the important salts of the sea. Recent biological studies have also shown that magnesium salts are to a certain extent deleterious to life processes. While the relation of life processes to environment is problematical, the evidence favors the physical control of life processes, rather than the control of environment by life processes.

Even if the immediate control of the evolution of carbonate rocks was largely by organic agencies, the causation of the control may logically be looked for in the environment. The change in the calcium magnesium ratio, which characterizes the evolution of the carbonate rocks, suggests under this hypothesis that it is related to a similar change in the calcium magnesium ratio of the materials contributed to the sea. It has been indicated already that waters containing a high proportion of magnesium to calcium are more efficient in causing the development of dolomite than those which do not. The salts of the sea are inherited from the metamorphic processes which have worked the earth over and over again. The circulation of the rock materials from one environment to another involves adaptations. The materials adapted to the new conditions tend to be stable. Others undergo conversion to new mineral forms. Some, finding no place in the new environment, are expelled and may finally reach the sea, where they again undergo environmental adaptations. Could it be possible that the ratio of river-borne calcium to magnesium, which is now approximately 6 to 1, has undergone an evolution throughout geologic times marked by a gradual increase in calcium and decrease in magnesium? A progressive change in the proportions of calcium and magnesium contributed to the sea might have been consummated either by a progressive change in the agents and processes of

metamorphism and sedimentation or by a progressive change in the calcium and magnesium content of the lands. It cannot very well be assumed that the nature of the agents and processes which contribute calcium and magnesium to the sea has undergone any marked change during geologic time. The continuity of the life record, the uniformity of sedimentation, and the duplication of climatic conditions down to the remote past speak against it. How then could the constitution of the lands, apparently the only remaining alternative, undergo a progressive change which in turn caused a progressive increase in the ratio of calcium and magnesium contributed to the sea, under uniformitarian processes? The answer to this problem is sought in the nature of the redistribution of calcium and magnesium in consequence of metamorphic and depositional processes.

[*To be continued*]

THE RECURRENCE OF TROPIDOLEPTUS CARINATUS IN THE CHEMUNG FAUNA OF VIRGINIA[1]

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For many years after the standard sections of the New York Devonian formations and their faunas had become well known, the brachiopod *Tropidoleptus carinatus* was supposed to be confined in its geologic range to the 1,100 or 1,200 feet of shale comprising the Hamilton formation in central New York. No trace of this fossil has ever been found in the typical Genesee and Portage faunas which follow the Hamilton fauna in west central New York. The entire absence of the species from the Genesee and western Portage faunas of New York seemed to indicate that the life of the species came to an end with the close of Hamilton sedimentation in central New York. But the discovery of *T. carinatus* in the Chemung of southern New York 2,000 feet above the top of the Hamilton by Professor H. S. Williams[2] several years ago proved that this species instead of becoming extinct at the close of the Hamilton had only changed its habitat. More recently Williams and Kindle[3] have found that *Tropidoleptus carinatus* and other well-known Hamilton species comprise the major part of the fauna at certain Chemung horizons in southern New York 2,000 feet or more above the top of the Hamilton formation. In this paper it will be shown that this and other Hamilton species reappear in the Chemung fauna of Virginia as they do in New York. The appearance of *T. carinatus* in the Chemung fauna of Virginia in abundance is especially notable because it is seldom found at the horizon of the Hamilton fauna so far to the southwest in this part of the Allegheny region as the occurrence in the rocks of Chemung time which will be described.

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] *Bull. U.S. Geol. Survey No. 3* (1884), 24.

[3] *Amer. Jour. Science*, XIII (1902), 427–30; *Bull. U.S. Geol. Survey No. 210* (1903), 90–91.

This recurrent Hamilton fauna was collected in Bath County, Virginia, near Mountain Grove post-office. The relationship which it bears to the other faunas which are known in the section from which it comes will be indicated by the following section of the rocks exposed along Little Creek at Mountain Grove post-office.

SECTION AT MOUNTAIN GROVE, VA.

	Feet
h. Thin-bedded, hard, gray sandstone and interbedded shale	700
g. Thin-bedded, hard, gray sandstone and interbedded shale	100
f. Rather hard, sandy, dark-blue shale and some thin bands of sandstone with Portage fauna	600±
e. Black, hard fissile shale	100
d. Covered	70
c. Hard, black, and dark greenish-gray calcareous shale	6
b. Black, blocky, tough shale	20
a. Dark, coarse, ferruginous sandstone with frequent concretions of pyrites (Oriskany)	20+

The sandstone at the base of the section holds the usual type of Oriskany fossils and clearly represents the Oriskany sandstone. The fauna of the lower 26 feet of calcareous and blocky shale is rather meager in this section as compared with the rich fauna often found at this horizon. The species collected from it are the following:

FAUNULE *c*, MOUNTAIN GROVE, VA.

Orbiculoidea lodiensis media	*a*
Anoplotheca acutiplicata	*c*
Conularia sp.	*r*

This faunule taken alone, of course, could hardly be cited as satisfactory evidence of a definite horizon. An extended study[1] of the fauna found at this horizon by the writer throughout an extensive region in the Allegheny Mountains has shown, however, that the horizon is that of the Onondaga limestone. The greater part of the Hamilton horizon is covered in the section.

The next higher fauna which was collected from this section is shown in the following list of species from the lowest beds in the sandy shales marked *f* in the section outcropping at Cash's store.

[1] *The Onondaga Fauna of the Allegheny Region*, Bull. U.S. Geol. Survey (in press).

FAUNULE *f*, MOUNTAIN GROVE, VA.

Ontaria suborbicularis
Paracardium doris
Styliolina fissurella
Bactrites aciculum
Orthoceras sp.
Probloceras cf. lutheri
Tornoceras uniangulare

The student familiar with the western Portage or *Buchiola retrostriata*[1] fauna will at once recognize in this faunule a representative of that fauna. Its occurrence at a definite horizon in Virginia and Pennsylvania has been previously noted by the author.[2] Clarke[3] and Swartz[4] have recognized the same fauna in western Maryland. It should be noted here that the *Buchiola retrostriata* (*G. speciosa*) fauna listed by the author from the White Sulphur Springs, Virginia,[5] section is not the faunal equivalent of the *B. retrostriata* (*G. speciosa*) fauna of Williams,[6] but comprises only the upper portion of Williams' fauna. As the term is used by Professor Williams in Bulletin 244 it includes at least three distinct faunas, each of which has a fairly definite position in the sections. The writer's past and present usage makes it include only the latest of these three—the Portage—thus making it synonymous with the western Portage or Naples fauna of New York. The recorded range of this species makes it permissible to use the name in Professor Williams' comprehensive manner if it is desirable to consider these several faunas collectively. But the writer prefers the more restricted usage adopted by Professor Williams in an earlier paper,[7] according to which it includes only the western phase of the Portage fauna. The Portage fauna appears to characterize about 600 feet of the Mountain Grove section. Although the section is mostly exposed and the order of succession of the different parts is clear, the local buckling of

[1] This fauna has also been called the *Manticoceras intumescence* fauna and Naples fauna in New York.

[2] *Bull. U.S. Geol. Survey No. 244* (1905), 35, 40–41; *Jour. Geology*, XIV (1906), 633.

[3] *N.Y. State Mus. Mem. 6* (1904), 212.

[4] *Jour. Geology*, XVI (1908), 340.

[5] *Bull. U.S. Geol. Survey No. 244* (1905), 35.

[6] *Ibid.*, 51.

[7] *Bull. U.S. Geol. Survey No. 210* (1903), 115.

some of the softer beds leaves some uncertainty regarding the exact thickness of the section.

It is with the next fauna in the section that this paper is chiefly concerned. This fauna appears after the bluish-gray sandy shales and very thin sandstones have given place to very hard thin-bedded sandstones as the dominant lithologic characteristic of the section. In beds of this kind in division *g* of the section occurs the first appearance of the Chemung fauna. The following is a list of the species collected from this horizon:

FAUNULE *g*, MOUNTAIN GROVE, VA.

Productella sp.	*c*
Camarotoechia cf. congregata	*c*
Leiorhynchus sp.	*c*
Atrypa spinosa	*c*
Rhipidomella impressa	*r*
Rhipidomella cf. penelope	*r*
Schizophoria tioga	*c*
Ambocoelia umbonata	*c*
Schuchertella chemungensis	*r*
Delthyris mesacostalis	*c*
Spirifer medialis	*c*
Reticularia fimbriata	*r*
Tropidoleptus carinatus	*a*
Mytilarca chemungensis	*r*
Modiomorpha sp	*r*
Nuculites cf. oblongatus	*r*
Cyclonema sp.	

The stratigraphic position of this fauna several hundred feet above a typical Portage fauna shows plainly that it lies far above the Hamilton horizon. Its association with *Schizophoria tioga* and *Mytilarca chemungensis* indicates that it is here associated with a Chemung fauna. In the next division of the section above this we find *Spirifer disjunctus* and other well-known Chemung fossils as shown in the following list from division *h* of the section:

FAUNULE *h*, MOUNTAIN GROVE, VA.

Aulopora sp.	*r*
Chonetes scitula	*c*
Productella hirsuta	*c*

Atrypa spinosa	*c*
Stropheodonta (Douvillana) mucronatus	*a*
Stropheodonta perplana var. nervosa	*r*
Schizophoria tioga	*c*
Rhipidomella sp.	*r*
Camarotoechia sp.	*r*
Spirifer disjunctus	*c*
Edmondia sp.	*r*
Schizodus rhombeus	*r*
Sphenotus contractus	*c*
Loxonema sp.	*r*

The case of recurrence which has been cited involves a somewhat different phase of the phenomenon from that represented in the New York occurrences of *T. carinatus* in the Chemung.

The presence of a recurrent Hamilton species like *Tropidoleptus carinatus* in the Chemung fauna of southern New York involves its withdrawal from at least the major part of the New York area at the end of Hamilton sedimentation to some part of the sea furnishing a more congenial environment than that which accompanied Genesee and Portage sedimentation. In the newly adopted habitat or in a small portion of the old one it found a haven where those conditions of the Hamilton sea which were essential to its life were maintained throughout Genesee and Portage time. With the initiation of Chemung sedimentation *T. carinatus* extended its habitat back again over a part of the area which it had previously occupied.

The case of recurrence which I have given in Virginia does not involve, as in New York, a retreat of the species before unfavorable conditions at the close of the Hamilton and later recovery of lost territory, since it apparently never occupied this territory in Hamilton time. It represents instead the acquisition of a new habitat which had been outside the limits of its geographical range in the Hamilton sea. The writer's study of the Devonian faunas in the Allegheny region indicates that the typical Hamilton fauna with *T. carinatus* does not extend as far to the southwest as Mountain Grove, although the Hamilton sea extended much beyond that point to the southwest. The occurrence of a Hamilton species in abundance in the Chemung fauna of this part of Virginia thus

seems to indicate that the marine biotic conditions of the New York Hamilton and the Virginia Chemung seas were more nearly alike than they were in different parts of the same sea in the two states during Hamilton sedimentation.

A matter of some interest and importance in connection with the recurrence of this species and its associates relates to the location of its Portage habitat, or place of retreat between the close of Hamilton and the beginning of Chemung sedimentation. It has been shown by Prosser[1] and others[2] that in eastern New York the Hamilton fauna including *Tropidoleptus carinatus* continued in a slightly modified form to live on during Portage time. In other words, this species and some of its allies at the close of Hamilton time became extinct in central and western New York but survived in a narrow belt along the eastern margin of their old habitat and continued to live near the eastern shore of the Appalachian Gulf throughout Genesee and Portage time. (See Fig. 1.)

In Pennsylvania the writer's work has shown that the Ithaca and Portage faunas bear the same geographic and stratigraphic relations to each other that they do in New York. In western Pennsylvania the Portage formation is characterized by a typical western Portage or Naples fauna.[3] On the Susquehanna River an Ithaca fauna occupies the same horizon which is held by the Portage fauna in the Altoona section.[4] East of the Susquehanna River 35 miles, at Pine Grove, the writer has recently collected a faunule of the Ithaca fauna which shows a more prominent Hamilton element than the fauna exhibits at the Susquehanna River. It includes *Tropidoleptus carinatus*, as will be seen from the following list of its species:

[1] "The Classification and Distribution of the Hamilton and Chemung Series of Central and Eastern New York," *Fifteenth Ann. Rep. State Geol. New York* (1897), 208–14.

[2] H. S. Williams, "The Correlation of Geological Faunas," *Bull. U.S. Geol. Survey No. 210* (1903), 71–72; John M. Clarke, "The Ithaca Fauna of Central New York," *Bull. N.Y. State Mus. No. 82* (1905), 53–65.

[3] E. M. Kindle, "Faunas of the Devonian Section near Altoona, Pennsylvania," *Jour. Geology*, XIV (1906), 633.

[4] H. S. Williams and E. M. Kindle, "Contributions to Devonian Paleontology, 1903," *Bull. U.S. Geol. Survey No. 244* (1905), 69–92.

ITHACA FAUNA AT PINE GROVE, PENNSYLVANIA

Aulopora sp.	*r*
Cystodictya meeki	*c*
Chonetes scitula	*a*
Spirifer pennatus var. posterus	*a*
Tropidoleptus carinatus	*c*
Palaeoneilo plana	*c*
Modiomorpha cf. subalata	*r*
Goniophora minor	*r*
Paracyclas liratus	*r*
Actinopteria peristralis	*c*
Coleolus aciculum	*r*
Pleurotomaria capillaria	*r*
Pleurotomaria sulcomarginata	*c*
Murchisonia cf. leda	*r*

From central and eastern Pennsylvania the Ithaca fauna extends southward across Maryland far into Virginia. The Portage and Ithaca faunas occupy the same relative stratigraphic and geographic positions in this southerly area[1] as in New York state, the former having its maximum development to the westward of and parallel with the Ithaca fauna. Evidence that *Tropidoleptus carinatus* lived during Portage time near the eastern margin of the Appalachian Sea in Virginia as well as in Pennsylvania and New York is furnished by a collection representing the Ithaca fauna which the writer made at Bells Valley, Virginia. In this collection *T. carinatus* is a very abundant species, while another pre-Portage species, *Rhipidomella vanuxemi*, occurs sparingly with it.

The relation which *Tropidoleptus carinatus* bears to Hamilton, Portage, and Chemung sediments may be illustrated by the accompanying diagram which shows the easterly restriction of the species in New York during Portage time and the westerly extension of its habitat during Chemung time. The easterly or coastwise restriction of the species at the close of the Hamilton could be graphically shown for Pennsylvania and Maryland by diagrams of similar character, except that the Tully limestone would be omitted.

[1] E. M. Kindle, *Bull. U.S. Geol. Survey No. 244* (1905), 35, 41, faunules 1380*B* and 1382*D;* Charles K. Swartz, *Jour. Geology*, XVI (1908), 328–46.

When it is recalled that the geographic range of this species in the eastern United States during the Hamilton extended from the Hudson River and the eastern part of the Allegheny Mountains to Michigan, Indiana, and southwestern Illinois, it will be seen that its east-west distribution was reduced during Portage time to a very small fraction of that which it enjoyed during Hamilton time. Our present knowledge of its occurrence in the Chemung indicates that only a very small part of its east-west Hamilton range was regained during the Chemung. The north-south distribution of the species in the Allegheny region did not, however,

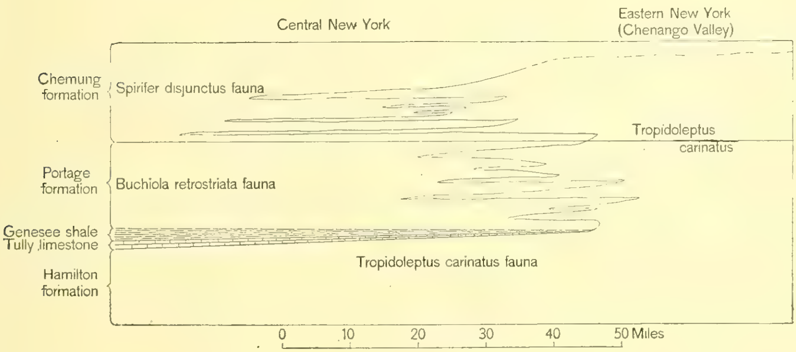


FIG. 1.—A diagrammatic east-west cross-section of the Middle and Upper Devonian of southern New York showing the relations of *Tropidoleptus carinatus* to the western faunas during Portage and Chemung time. Total thickness of the section is about 2,700 feet.

differ greatly during the Portage and Chemung epochs from what it had been during the Hamilton. In this direction it appears to have extended its range slightly in Chemung time beyond what it had been during Hamilton time. During Portage time the species was confined to a sublittoral belt, narrow but long, which reached south into Virginia along the eastern shore of the Appalachian sea. From the limits of this coastwise belt of the sea the more favorable conditions of environment which accompanied the initiation of Chemung sedimentation encouraged the migration of its colonies westward into the areas where we now find them in the Chemung of New York and Virginia. These colonies

appear to have experienced a succession of alternate extensions and withdrawals in the New York Chemung.

It is essential to a clear understanding of the interrelationship of these distinct but contemporaneous faunas to recognize the fact that zoölogical provinces were often as distinct in the Paleozoic seas as in those of the present. In the Devonian we know that there were such provinces, but as yet we know but little of their limits in any given epoch. We also know comparatively little about the factors which set the limits to faunal provinces. It is safe to conclude, however, that the recurrence of a fauna has been due to the oscillation or migration of the factors which conditioned its geographical distribution. Attention has been called to one of these factors by Ulrich[1] in discussing the recurrence of a Spergen fauna in the Ste. Genevieve limestone. He conceives one of the conditions inducing the recurrence of this fauna to have been "the subsidence or modification of barriers allowing communication with seas more permanently inhabitated by the invading fauna." The probable combination of two factors which are no doubt often effective in controlling recurrence is cited by Bagg in discussing the recurrence of a Cretaceous brachiopod in the Eocene of Maryland. Bagg[2] believes this case of recurrence to have been due to a deepening of the sea south of New Jersey, assisted perhaps by cold currents from the north which killed off the other Cretaceous species and encouraged the southward migration of a shell which previously had lived in the New Jersey region.

While the development or removal of land barriers and changes in the character of sediment have doubtless been at times influential in causing the recurrence of faunas, it is probable that changes in the temperature of marine waters have much more frequently been the direct effective agency in causing recurrence. Among the agencies controlling faunal distribution it is most probable that temperature has in the past, as in the present, been a factor of paramount importance. The recurrence of a species necessarily represents the recurrence of those factors in its environment which

[1] *Prof. Paper U.S. Geol. Survey No. 36* (1905), 49.

[2] *Am. Geologist*, XXII (1898), 272–373.

have throughout its life history controlled its distribution. Recurrent faunas, therefore, afford special opportunities to discover the factor most essential to the life of the fauna in a given case through elimination of those factors which are common to the sediments from which it is absent and in which it makes its earlier and later appearances. With reference to the sediments, the recurrence of a species after long absence from the section thus affords evidence of similar conditions having been present in widely separated formations, the importance and significance of which might otherwise not have been apparent.

In the light of these general considerations we may inquire into the cause of the eastward retreat of the species which has been shown to have occurred at the beginning of Genesee sedimentation and its later westward and southwestward migration. The evidence of such a movement has been cited on a preceding page. The close of Hamilton sedimentation is marked in western New York by a great change in the character of the sediments. The sandy and often calcareous shales of the Hamilton are succeeded by the thin band of the Tally limestone and the fissile black carbonaceous shales of the Genesee in the central and western parts of the state (see Fig. 1). When these black Genesee and the succeeding lighter-colored shales of the Portage are not entirely barren they are occupied by a fauna of "evident deep-water habit having nothing in common with the preceding Hamilton fauna."[1] These black shale sediments following the Hamilton extend southward beyond the Potomac River. This sharp contrast between the sediments and faunas of the Hamilton and those of the Genesee shales includes the total disappearance of the large coral fauna of the Hamilton. The annihilation at the close of the Hamilton of all fossils which, like corals, require shallow waters, and the shifting of those species which survived to the comparatively shallow coastwise waters points plainly to the deepening of the sea at the close of Hamilton time. Much additional evidence for the deep-sea conditions which prevailed during Genesee and Portage time in western New York

[1] John M. Clarke, "The Naples Fauna in Western New York," *N.Y. State Mus. Mem. No. 6* (1904), 211.

has been given by Dr. John M. Clarke[1] and requires no restatement here. A lower temperature of the water doubtless accompanied the deepening of the sea during early Genesee time and was probably the chief immediate cause of the complete disappearance of the shallow water fauna of the Hamilton from a large part of the Devonian sea with the appearance of the pelagic Genesee fauna. The sea became shallow again during Chemung time. This is shown by the ripple-marked sandstones which may be seen in Chemung sediments from New York to southern Virginia. That the remnant of the Hamilton fauna which had survived till Chemung time in the shallow coastwise waters in the eastern margin of the Devonian sea found in the Chemung sea a temperature similar to that of the old Hamilton sea is attested by such colonies as the one which has been described from Virginia.

The distribution of *Tropidoleptus carinatus* in the Chemung sediments as detached, often widely separated, colonies is in some degree comparable with that of *Ostrea virginica* along the present Atlantic coast. This warm-water species is unknown along wide stretches of the northern New England coast but in the Gulf of St. Lawrence flourishes in waters, which in their deeper parts afford a habitat for such Arctic forms as *Mya truncata*. That a low temperature is as essential to the life of the latter as is a high temperature to the former is illustrated by the fact that while in the Gulf of St. Lawrence *M. truncata* is found in the deeper waters only, in Greenland waters it is said to be sufficiently common at low water to furnish food for the Arctic fox and other land animals.[2] The character of the geographical conditions which permit representatives of the south Atlantic and north Atlantic coast faunas to live on adjacent parts of the sea bottom is indicated in the following quotation from Doctor MacBride.

> The whole north coast of Prince Edward Island is fringed by a series of parallel sand-bars, and it is owing to this circumstance that the oyster is able to flourish there. All who know the coast of the Gulf of St. Lawrence are aware that the water even in summer is very cold; so cold indeed that though

[1] *Op. cit.*

[2] J. F. Whiteaves, *Catalogue of the Marine Invertebra of Eastern Canada* (Geol. Surv. of Canada, 1901), 148.

the adult oyster could live in it, it could not reproduce itself, for the larvae would perish. But as the Gulf water flows over the sand-bars and shoals alluded to, it becomes heated up by the summer sun, and reaches a temperature which permits, in favorable years at least, of successful spawning. Oysters are accordingly confined to such places on the coast of Canada as present conditions similar to those mentioned above. They exist in the Baie de Chaleur, in some of the shallower inlets on the New Brunswick coast, at a few points on both shores of Prince Edward Island, and on the Northern Coast of Nova Scotia. In every case, however, we have to do with isolated colonies inhabiting warm spots surrounded by a great belt of cold water, so that although the larvae could be carried to great distances in the fortnight of their free-swimming life, they are all killed off by the cold.[1]

Protecting bars may at times have been a factor in modifying the temperature of the Devonian sea where Portage and Chemung colonies of *T. carinatus* gained a foothold, as they are now in sheltering the oyster at Prince Edward Island. But there can be no doubt that all times during the upper Devonian the eastern or coastwise belt of the Appalachian gulf was shallower than its more pelagic portion. Its waters must also have been comparatively warm, at least during the spawning season of its molluscan fauna. Since *Tropidoleptus carinatus* is confined in the late Devonian to the sediments of this belt of comparatively shallow sea, and consequently warmer water, we must conclude that its restriction and late survival here was due primarily to the higher average temperature of this part of the Devonian sea.

[1] E. W. MacBride, "The Canadian Oyster," *Canadian Rec. of Sci.*, IX (1905), 154–55.

FURTHER DATA ON THE STRATIGRAPHIC POSITION OF THE LANCE FORMATION ("CERATOPS BEDS")[1]

F. H. KNOWLTON

In June, 1909, I published a paper entitled: "The Stratigraphic Relations and Paleontology of the 'Hell Creek Beds,' 'Ceratops Beds,' and Equivalents, and Their Reference to the Fort Union Formation."[2] In that paper, as suggested by the title, the conclusion was reached that the beds considered—namely, the "Hell Creek beds," "Ceratops beds," "somber beds," and "Laramie" of many writers—are "stratigraphically, structurally, and paleontologically inseparable from the Fort Union, and are Eocene in age."

It was expected that this somewhat radical innovation would be received with a storm of protest, especially by the vertebrate paleontologists, but so far as known to the author only three papers have since appeared which deal specifically with the position of the "Ceratops beds." These comprise two papers by Dr. T. W. Stanton and one by Dr. O. P. Hay.

As two field seasons have intervened since the publication of my paper, during which important data were secured confirming the position there assigned the Lance formation,[3] it seems opportune to present the case as it now stands. The areas in which these observations were made are in the main in Eastern Wyoming and Eastern Montana and adjacent portions of North and South Dakota.

[1] Published with the permission of the Director of the U.S. Geological Survey.

[2] *Proc. Wash. Acad. Sci.*, XI (1909), 179–238.

[3] The name *Lance formation* has been formally adopted by the U.S. Geological Survey in place of the term "Lance Creek beds" or "Ceratops beds." Wherever *Lance formation* is employed in the following paper it is to be understood as including "Lance Creek beds," "Ceratops beds," "Hell Creek beds," "somber beds," "Lower Fort Union," and beds identified as "Laramie" by many writers.

NEAR THE MOUTH OF THE MEDICINE BOW RIVER, CARBON COUNTY, WYOMING

In the early nineties, when the late J. B. Hatcher was searching for new fields that might possibly supply additional material belonging to the then recently discovered group of horned dinosaurs (Ceratopsidae), he made an examination of the country lying along the North Platte River some twenty-five or thirty miles north of old Fort Fred Steele, in Carbon County, Wyoming. Hatcher observed fragmentary remains of dinosaurs at a point which he indicated[1] as "on the North Platte River opposite the mouth of the Medicine Bow River." As the dinosaurian remains were neither abundant nor well preserved, the country was not again visited until 1906, when a party from the United States Geological Survey, under the direction of Mr. A. C. Veatch, was engaged in investigating the coal resources of the so-called Carbon County coal-field. Veatch[2] published an outline geological map on which was shown the areal distribution of the formations involved. From this map it appeared that strictly speaking a point "opposite the mouth of the Medicine Bow River" would fall within Veatch's so-called "Lower Laramie,"[3] which is there 6,500 feet in thickness. Unfortunately Veatch did not collect any dinosaurian remains and thus settle definitely their position in this section, but from residents of the region who had known of Hatcher's discoveries it was pretty clearly indicated that they came from a series of low bluffs about a mile up the North Platte River from a point opposite the mouth of the Medicine Bow, in beds belonging to Veatch's so-called "Upper Laramie," which are in part at least the equivalent of the "Ceratops beds" of Converse County. The question of the absolute stratigraphic position of these dinosaur-bearing beds was thus held in abeyance until the past season (1910), when Dr. A. C. Peale and the writer spent ten days in the region, during which we secured data which settled

[1] *Am. Nat.*, XXX (1896), 118.

[2] *U.S. Geol. Surv.*, *Bull. 316* (1907), 244, Pl. XIV.

[3] The "Lower Laramie" of Veatch is the same as the Laramie of the Denver Basin of Colorado as shown by its stratigraphic position and contained fossils. See Veatch, *Jour. Geol.*, XV (1907), 526–49.

the matter definitely. Incidentally it may be mentioned that we were able to confirm in every particular Veatch's mapping of the formations in this vicinity.

On the west side of the North Platte River, opposite the mouth of the Medicine Bow River, the bluff in the "Laramie" is about a mile back from the river. The beds, which consist of alternations of soft shales and beds of shaly brownish sandstones and numerous thin beds of coal, dip to the southeast at angles between 20° and 25°. From the bluff the surface slopes gently to the stream, and exhibits admirable exposures throughout. A very careful search was made of the "Lower Laramie" section, and although invertebrates pronounced by Dr. Stanton to be of "Laramie" age were found at numerous horizons, not a scrap of bone could be detected.

The contact between the "Lower Laramie" and "Upper Laramie" is very distinct and undoubtedly has been correctly placed by Veatch. There is a distinct change in the dip, apparently a slight change in the strike, and a marked change in the lithology between the lower and upper beds. The basal 300–400 feet of the beds above the line are composed of somber-colored soft sandstones and shales, often cross-bedded, with occasional small ironstone concretions, and in every way suggest the "Ceratops beds" to the northeast. Fragments of bone are scattered over the surface, and although no large pieces were secured at this particular point, enough was found to prove the presence of turtles, crocodiles, and dinosaurs. On the strike of these beds at a point about six miles southeast (T23N, R84W) we found in place about 300 feet above the base of the "Upper Laramie" beds a number of large vertebrae. These have been studied by Mr. C. W. Gilmore of the U.S. National Museum, and Mr. Barnum Brown of the American Museum of Natural History, and by both pronounced unqualifiedly to belong to *Triceratops*. It is not possible to fix with certainty the species to which these vertebrae belong, since the characters separating the species are drawn mainly from the skull, but Mr. Gilmore permits me to say that it is impossible to distinguish them from vertebrae of certain species from Converse County in which both skull and vertebrae are known. It

is quite possible that the skull of the individual of which we secured the vertebrae could be recovered by more extended excavation than we were able to make with the implements at hand.

Since, with the exception of their occurrence in the post-Laramie formations of the Denver Basin, the remains of *Triceratops* have never been found outside the Lance formation, the finding of *Triceratops* at this point is of far-reaching importance. It shows that not only are the beds containing them *above* more than 6,000 feet of "Laramie" rocks (the basal portion of which is almost certainly of Fox Hills age), but also that they are separated from the "Laramie" ("Lower Laramie") by an unconformity, which, according to Veatch,[1] is profound and has involved the removal of perhaps as much as 20,000 feet of sediments. This would seem effectively to dispose of the contention that the Lance formation ("Ceratops beds") is the equivalent of the Laramie.

The Lance formation—for such it must now be called—along the North Platte River above (south of) the mouth of the Medicine Bow, passes virtually without known stratigraphic break into beds which some twenty-five miles to the south have yielded Fort Union flora, thus showing the similarity of this section with all other known sections in which both Lance formation and Fort Union are present.

About 25 feet below the horizon of the *Triceratops* vertebrae, in the area under discussion, we collected the following species of plants:

Sabal grandifolia? Newb.
Populus amblyrhyncha Ward
Viburnum marginatum Lesq.
Sapindus sp.
Sassafras? sp. (Same as an unnamed species from the "Ceratops beds" of Converse County, Wyo.)

The palm, which is identified with some doubt as *Sabal grandifolia*, has a longer rachis than is usual in this species but is otherwise indistinguishable. It was described originally from the Fort Union near the mouth of the Yellowstone, and has been found subsequently at many localities in Montana, Wyoming, and Colo-

[1] *Am. Jour. Sci.*, XXIV (1907), 18.

rado. The *Populus* above mentioned has not been found outside the Fort Union. *Viburnum marginatum* was described first from Black Buttes, Wyoming, and has since been found in many places, among them several localities in the Lance formation of the Dakotas. The form identified as *Sassafras?* is a peculiar leaf and is apparently the same as an unnamed form from the Lance formation of Converse County. This analysis shows that three of the five forms noted in this collection are found in the Lance formation.

About five miles south of the above-mentioned *Triceratops* locality the "Upper Laramie" crosses the North Platte and the exposures are excellent. At this point the "Upper Laramie" consists of a great thickness of massive beds of yellowish and whitish sandstone, with much cross-bedding and abrupt changes from one color to another. Several hundred feet above the exposed base of this section we obtained a small collection of plants which embraces some three or four species, all of which are identical with undescribed forms from the Lance formation of Montana and the Dakotas.

The evidence of the plants is thus seen to confirm that of the vertebrates in correlating these beds with the Lance formation of Converse County and other areas in Montana and the Dakotas.

THE OLD STANDING ROCK AND CHEYENNE RIVER INDIAN RESERVATIONS

On the west side of the Missouri River, and lying between the Cannonball River on the north and the Cheyenne River on the south, is the area comprising in large part what was originally within the Standing Rock and Cheyenne River Indian Reservations. During the spring and early summer of 1909 this region was studied by a number of parties from the U.S. Geological Survey under the general charge of Mr. W. R. Calvert. The geology of this area is comparatively simple, the rocks being very little disturbed and at most comprising not more than four formations. Beginning with the lowest these are the Pierre shale, which is exposed in the valleys of most of the streams, and is overlain without stratigraphic break by the Fox Hills, which is the highest marine forma-

tion in the section. Above the Fox Hills, but, as will be shown later, with the intervention in places of a distinct unconformity, comes the Lance formation, above which, but without unconformity or other observed break, is the acknowledged Fort Union.

In the present connection the principal interest naturally centers in the Lance formation, and more particularly as regards its relation with the underlying Fox Hills. Mr. Calvert, who is not only familiar with the area in question but with adjacent areas in North Dakota and Montana where similar conditions obtain, has kindly prepared the following statement:

"Stratigraphic work by field parties in immediate charge of A. L. Beekly, Max A. Pishel, and V. H. Barnett in the Standing Rock and Cheyenne River Indian Reservations of North and South Dakota in 1909 and similar investigation in eastern Montana in 1910 in charge of Max A. Pishel and C. F. Bowen gave opportunity to study the relationship of several formations concerning which discussion has arisen periodically for a number of years, and which is of special interest in view of its direct connection with geologic history at the close of the Cretaceous. The region studied in the Dakotas includes the type locality of the Fox Hills sandstone and is adjacent to the type locality for the Pierre shale. Where the full section of the Fox Hills is present it usually comprises a gradation at the base from the somber shale of the typical Pierre into a more or less massive sandstone. This sandstone member is overlain by 25 feet or more of banded shale overlain in turn by a massive sandstone, constituting what in the field was considered the top member of the Fox Hills. Fossils occur only sparingly in the lower sandstone and in the banded shale, whereas the top sandstone is prolifically fossiliferous, the fossils being found most abundantly at or near the top of that member. Normally overlying this fossiliferous horizon is a sequence of beds entirely dissimilar in lithology from the underlying Fox Hills, and it is concerning these beds that question has arisen relative to their exact position in the geologic column. These strata constitute the Lance formation to which the name 'somber beds' has been applied in various previous publications.

"From the standpoint of lithologic character the term 'somber

beds' is very applicable, as the strata are made up chiefly of gray to dark clays and muds with intercalated lenticular sandstone members. There is rapid horizontal alteration in character of material so that a section measured at any one locality does not compare in detail with one measured a short distance away. Carbonaceous zones occur at frequent vertical intervals and the lowest few feet of the formation is almost invariably a lignitic zone.

"As a result of field study by Pishel, Barnett, and the writer, it seems certain that the line between the Fox Hills sandstone and the Lance formation is marked by an unconformity, but the import of that unconformity is of course a matter for the paleontologist rather than for the stratigrapher to decide. However, the evidence gathered by the stratigrapher may possibly have some weight in arriving at a conclusion, and that evidence is here presented.

"The maximum thickness of the Fox Hills sandstone is in the neighborhood of 200 feet, but it was found in the field that this measurement is entirely too great for certain localities. On Worthless Creek, in T16N, R20E, Black Hills Meridian, exposures are especially good and it was here that the most striking example of unconformity between the Fox Hills and Lance formation was observed. On the west side of Worthless Creek Valley, near the line between sections 25 and 26, it was noted that the 'somber beds' of the Lance formation transgressed across the Fox Hills sandstone and that the upper part of the latter formation down to the banded shale member was absent. The unconformity at this locality is angular as well as erosional, for the banded shale dips to the north at a 4-degree angle, whereas the 'somber beds' are horizontal. Within a horizontal distance of 500 feet the 'somber beds' fill a channel eroded in the banded shale of the Fox Hills, so that the total vertical amount of combined transgression and erosion is more than 40 feet. On the opposite side of the valley the total thickness of undoubted Fox Hills is even less, for it appears that the lignitic zone of the 'somber beds' rests on Pierre shale. In any event there is surely less than 25 feet of the Fox Hills present at this place. In view of the fact that the Fox Hills sandstone is normally at least 150 feet thick it would seem that

the erosion interval represented is of considerable magnitude, or else that the formation is peculiarly variable in thickness.

"In general the zone along the contact between the Fox Hills sandstone and the Lance formation is poorly exposed in this region, but in the majority of localities where exposures were adequate careful study disclosed evidence that deposition was not continuous from one formation into the other. In a paper[1] on this subject Doctor Stanton admits the occurrence of an unconformity at this horizon in the Dakotas but attaches no particular significance thereto, stating that channeling would normally be expected in the change from marine to land conditions and giving especial weight to the fact that a marine Fox Hills fauna is found commingled with brackish-water types above the unconformity. He states that 'The paleontologic evidence consists of distinctive Fox Hills species belonging to such marine genera as Scaphites, Lunatia, and Tancredia, found directly associated in the same bed with the brackish-water forms and occurring with them in such a way that they must have lived together or near each other and been imbedded at the same time.'

"From the above quotation the inference is plain that Dr. Stanton concludes that the faunal evidence demonstrates with a fair degree of certainty that the unconformity is of minor rather than of major significance. To this conclusion the stratigrapher, is, of course, not qualified to object with authority, but it seems to the writer that the evidence may be looked at from two divergent points of view. Because Fox Hills fossils occur in the lignitic shales at the base of the 'somber beds' and mingled with the brackish water types of the Lance formation is not necessarily proof positive that the various faunas lived at the same time; for if the deposition of the Fox Hills was followed by a definite erosion interval, what is more probable than that in the deposition of succeeding strata fossil shells would be eroded from the marine beds and carried into channels, there to mingle with the then living brackish-water fauna of the Lance formation?

[1] T. W. Stanton, "Fox Hills Sandstone and Lance Formation ('Ceratops Beds') in South Dakota, North Dakota and Eastern Wyoming," *Am. Jour. Sci.*, XXX (1910), 178.

"That the unconformity at this critical horizon is of more than local significance is borne out in large measure by observations made in the course of an examination of the lignite region in eastern Montana in 1910. Trending southeast from Yellowstone River, 10 miles southwest of Glendive, is an anticline which extends to the South Dakota line and along which the Lance formation is exposed in a zone on either side. Along the axis of this anticline Pierre shale is at the surface in a band several miles in width with a sandstone formation appearing as a zone of outcrop between it and the Lance. Although fossils have not been found in this sandstone it is believed to be the equivalent of the Fox Hills in

FIG. 1.—South bank Moreau River, near Govert P.O., South Dakota, showing angular unconformity between Lance and underlying beds identified as Fox Hills. Photograph by Barnett.

its type locality. Transition into it from the Pierre shale is perfect, and as in the Dakotas it is overlain by the markedly dissimilar strata composed of alternating lenticular sandstone, somber clays, and carbonaceous zones. In at least two localities in this region the upper surface of the sandstone referred to the Fox Hills is irregular and with every appearance that sedimentation between that formation and the overlying Lance formation was interrupted. These were noted and mapped by Pishel and Bowen and are in Sec. 22, T6N, R60E, Sec. 32, T7N, R61R. The amount of erosion is not great in either case, but in the opinion of the writer the occurrence of an unconformity in this region at appar-

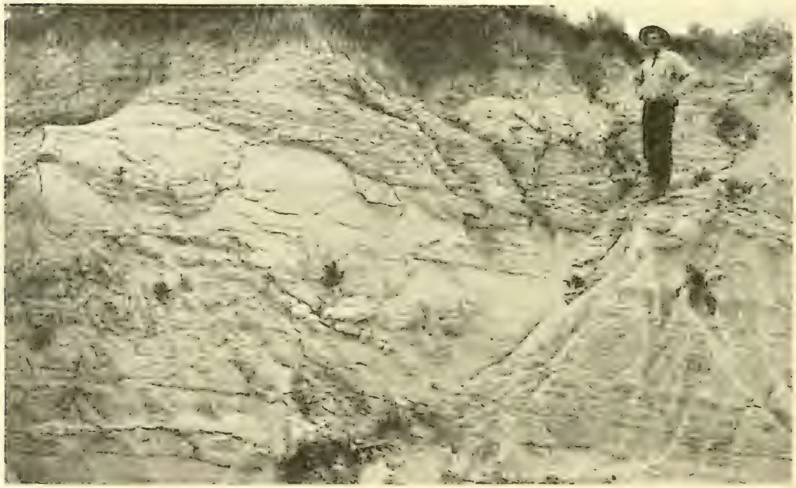
ently the same horizon as that in the Dakotas tends to show that the break has more than local significance."

The observations recorded by Mr. Calvert in the eastern portion of this South Dakota field were supplemented and extended to the western part of the state by Mr. V. H. Barnett in 1910, while making a hasty reconnaissance trip across the country. For instance, on the south bank of the Moreau River, near Govert P.O., in Sec. 21, T15N, R8E, South Dakota, Mr. Barnett found what is perhaps the most marked evidence yet recorded of unconformable relations between beds thought to be Fox Hills and the Lance formation. Mr. Barnett traced the Lance formation continuously from the central part of the state to the point mentioned above, where it was found practically horizontal, while the underlying beds dip to the northwest at an angle of about 10°. These underlying beds appear to be in the stratigraphic position of, and lithologically similar to, beds resting immediately on Pierre shale, at Hoover, about 10 miles southwest, and there is no reasonable doubt regarding their age, but no paleontologic evidence was secured—or sought—at this locality. If the beds are not of Fox Hills age they must be older, which would indicate an unconformity of even greater magnitude than is presumed. Mr. Barnett secured a photograph of this section which he has kindly permitted me to reproduce here as Fig. 1. The full section of the supposed Fox Hills is not exposed at this point, but some distance west, at Castle Rock Butte (T12N., R5E), the following section was measured; Pierre 50 feet; Fox Hills 125 feet; Lance formation 140 feet, the latter overlain by higher Tertiary.

The unconformity spoken of above by Calvert as occurring in Sec. 32, T7N, R61E, in Custer County, Montana, is on the west side of the anticline extending southeast from Glendive. It is clearly shown in the accompanying Figs. 2, 3, the negatives of which were made by Mr. C. F. Bowen, by whose consent they are included here. The Fox Hills with a thickness of about 70 feet dips at an angle of 5°, while the overlying Lance formation is horizontal.

Mr. Calvert's observations concerning the occurrence of the marine Fox Hills invertebrates in the basal members of the Lance

formation may be briefly alluded to. It appears that in the hundreds of localities throughout the Dakotas, Wyoming, and Montana at which the contact between Fox Hills and the Lance



Figs. 2, 3.—Eastern part of Custer County, Montana, showing erosional unconformity between Fox Hills and Lance. Photographs by Bowen.

formation has been examined, only five localities, all within a limited area in South Dakota, have been noted in which the marine Fox Hills invertebrates occur above the acknowledged top of the Fox Hills, where they are often found commingled with certain

brackish-water forms. It does not appear that they have ever been found at a greater distance than 12 or 15 feet above the top of the Fox Hills, and since it further appears that in none of the four sections given[1] does the Fox Hills exceed 115 feet in thickness, there is every probability that they were re-deposited in the channeled upper surface of the Fox Hills and that they did not live in association with the brackish-water forms with which they are now found entombed.

The plant collections obtained from the Lance formation by Mr. Calvert and the members of the several parties under his charge show conclusively that the relation of this flora is unmistakably with the Fort Union. In fact with the information at hand regarding distribution it is practically impossible without stratigraphic data to distinguish between the flora of the Lance formation and that of the acknowledged Fort Union. The lists of these collections follow:

[5437]. NW ¼ Sec. 5, T2N, R88W, S. Dakota. North bank of Cannonball River, at McCord coal-bank, 150 feet above base of beds.

Sequoia nordenskiöldi Heer
Thuya interrupta Newb.
Glyptostrobus europaeus Unger
Populus speciosa Newb.
Populus amblyrhyncha Ward
Paliurus colombi ? Heer
Sapindus grandifoliolus Ward
Celastrus alnifolia ? Ward
Juglans sp. ?
2 new forms, gen. ?

[5443]. SW ¼ Sec. 23, T23N, R21E, Black Hills Meridian, 150 feet above base of beds.

Sequoia nordenskiöldi Heer
Leguminosites arachnioides Lesq.

[5444]. Near ¼ cor. E. side Sec. 13, T22N, R22E. Black Hills Meridian. 125 feet above base of beds.

2 or 3 of same species as unnamed forms from the "somber beds" at Glendive, Montana.

[5430]. Rattlesnake Butte, Cheyenne Indian Reservation, S. Dakota. 100 feet above base of beds.

Glyptostrobus europaeus Newb.
Taxodium occidentale Newb.

[1] *Am. Jour. Sci.*, XXX (1910), 174–77.

Viburnum marginatum Lesq.
Cornus newberryi Hollick
Salix sp.
Quercus sp.
3 or 4 forms that are identical with unnamed species from Glendive, Montana.

[5422]. Near SE $\frac{1}{4}$ Sec. 20, T14N, R19E, Black Hills Meridian, S. Dakota. 100 feet or less above base of beds.

Sequoia nordenskiöldi ? Heer
Sequoia langsdorfii Heer
Platanus platanoides ? (Lesq.) Kn.
Viburnum sp. (same as new species from Lance of Converse County, Wyoming).
Lauraceous leaf (same as form found in "somber beds" at Glendive, Montana).

[5431]. SW $\frac{1}{4}$ Sec. 4, T19N, R18E, S. Dakota. 300 feet above base of beds.

Thuya interrupta Newb.
Populus amblyrhyncha ? Ward
Viburnum elongatum Ward
Viburnum sp. ?
Grewiopsis whitei ? Ward

[5432]. SE $\frac{1}{4}$ Sec. 25, T20N, R18E, S. Dakota. 300 feet above base of beds.

Sequoia nordenskiöldi ? Heer
Zizyphus cf. Z. hyperboreus Heer
Populus ? sp.
Platanus ? sp.

[5433]. Sec. 33, T20N, R20E, S. Dakota. 150 feet above base of beds.

Ginkgo adiantoides Heer
Platanus raynoldsii ? Newb.
Sapindus grandifoliolus ? Ward
Viburnum (apparently same as unnamed species from Lance of Converse County, Wyoming).

[5434]. SE $\frac{1}{4}$ Sec. 12, T19N, R24E, S. Dakota. Base of beds. 3 fragmentary leaves, apparently same horizon as No. 5436.

[5436]. NE cor. Sec. 7, T17N, R24E, S. Dakota. Base of beds.

Platanus haydenii Newb.
Viburnum elongatum Ward
Viburnum marginatum ? Lesq.
Sapindus grandifoliolus ? Ward
Dombeyopsis sp.
Polygonum ? sp.
Lauraceous leaf like that of Glendive, Montana
2 species same as unnamed form from Glendive

[5423]. South of Moreau River about 7 miles above Thunder Butte P.O., S. Dakota.

Sec. 35, T14N, R19E. Lower 4 feet of Lance formation.

Thuya interrupta Newb.
Sequoia nordenskiöldi Heer
Sequoia acuminata ? Lesq.
Populus cuneata Newb.
Viburnum marginatum ? Lesq.
Leguminosites ? n. sp.
Cyperacites sp.
Monocotyledon—new

It needs but a glance at the above lists to show how preponderating is the Fort Union facies.

CONVERSE COUNTY, WYOMING

Although Converse County, Wyoming, is the type locality for the Lance formation, and has been visited again and again by geologists and paleontologists, it is still a perennial source of discussion and difference of opinion. From the first, difficulty has been experienced in drawing the line between the highest marine formation—the Fox Hills—and the overlying dinosaur-bearing beds. The Fox Hills was estimated by Hatcher to have a thickness of 500 feet, and consists of an alternating series of sandstones and shales, with massive sandstones at the top which contain numerous large concretions and a rich marine fauna of characteristic Fox Hills species. The upper line was drawn somewhat arbitrarily at a six-inch band of hard sandstone which was thought to separate the fossil-bearing Fox Hills sandstone below from similar but supposedly non-fossiliferous sandstones above. When Dr. Stanton and I visited this region in 1896 we failed to secure evidence for changing the top line of the Fox Hills as established by Hatcher, though we did find four species of brackish-water invertebrates in clays above a forty-foot bed of massive sandstone over 400 feet above the highest fossiliferous Fox Hills horizon in that particular section.

So the question rested until 1909, when Messrs. M. R. Campbell, T. W. Stanton, and R. W. Stone spent nearly a week in the region. Their principal contribution to the knowledge of the

stratigraphy of the area was, according to Stanton,[1] "the discovery that the marine Fox Hills deposits extend about 400 feet higher than had previously been determined, and that non-marine coal-forming conditions were temporarily inaugurated here before the close of Fox Hills time." If Hatcher's estimate of the thickness of the beds assigned by him to the Fox Hills was anywhere near correct this "discovery" would seem to increase the total thickness to about 900 feet, yet nowhere in the paper mentioned is a thickness greater than 400 or 500 feet claimed for it. This appears difficult to explain unless the lower as well as the upper limit of the formation has been changed.

A number of sections are given by Dr. Stanton, in one of which at least, namely that on Buck Creek, the top of the Fox Hills appears to have been fixed by the presence of the plant *Halymenites major*. The thickness of the Fox Hills in this section is given as 505 feet, though the highest horizon at which marine Fox Hills invertebrates occur is about 180 feet below the top.

In the section made on the divide between Lance and Buck Creeks the Fox Hills is said to have a thickness of 445 feet, though the lower member of the section only (30 feet above the Pierre shale) is indicated as containing a Fox Hills fauna.

The section made on the south side of the Cheyenne River at the mouth of Lance Creek shows a thickness of 405 feet of Fox Hills above the Pierre, but the highest point in the section at which marine Fox Hills invertebrates were found is over 100 feet below the top. It further appears from this section that the upper four members, aggregating 115 feet in thickness, contain carbonaceous and lignitic shales as well as fragments of dinosaur bone and brackish-water invertebrates, certain of which are the same as those found in, and there said to indicate the Laramie age of, the 400 feet of beds already mentioned as reported by Stanton and Knowlton above the typical marine Fox Hills.[2] To the writer it seems altogether more probable that the four upper members of this section belong to the Lance formation and not to the Fox Hills, and it appears that this was the view at first entertained by Dr.

[1] *Am. Jour. Sci.*, XXX (1910), 184.

[2] *Bull. Geol. Soc. Am.*, VIII (1897), 130.

Stanton, who says,[1] "When studying the section it was believed that the upper four members belong to the Lance formation, but afterward when comparison was made with sections of the south end of the field it seemed more possible that all the beds examined here belong to the Fox Hills." If this portion of the section is placed in the Lance formation, where it certainly appears to belong, the thickness of the Fox Hills in the section is reduced to 285 feet, or but little more than half of the maximum thickness assigned to beds of this age in the Converse County region. While this evidence may not be considered conclusive, it must at least be admitted that it strongly suggests the possibility that even here, as in the areas already discussed in the Dakotas and Montana, the Fox Hills is of variable thickness, due to the erosion of the upper portions before the deposition of the Lance formation.

It is to be admitted, however, that all who have studied the Converse County areas have had, and still have, difficulty in fixing the upper line of the Fox Hills, but in this connection it is to be pointed out that while many students have visited or collected in the region, it still awaits the careful, painstaking study that has been given other fields, such, for instance, as the areas in the Dakotas and Eastern Montana, which have been described by Mr. Calvert. And in this connection it may be mentioned that although in Converse County the exact location and extent of the unconformity between Fox Hills and Lance is not definitely known, the time interval is undoubtedly indicated, since 150 miles to the southeast (i.e., opposite the mouth of the Medicine Bow River) the same dinosaur-bearing beds are above an unconformity which separates them from 6,000 feet of unquestioned "Laramie," while 100 miles to the east in the Dakotas, the Lance formation rests on an uneven surface which in some cases represents the removal of practically the whole thickness of the Fox Hills of the region.

As a possible explanation of the difficulty experienced in detecting the presence of the unconformity between the Fox Hills and overlying Lance formation in this area, the following facts may be offered: the localities in Eastern Montana and Western South Dakota where the examples of the distinct angular and erosional

[1] *Am. Jour. Sci.*, XXX (1910), 185.

unconformity are so well exhibited are all adjacent to the anticlinal uplift which Calvert has shown extends southeast from the vicinity of Glendive, Montana, to the western line of the Dakotas. Here the uplift tilted the beds and accelerated the erosion, while in the flat country to the westward in Converse County and adjacent areas, the erosion of the Fox Hills was relatively uniform, and when the Lance formation was later laid down over this surface the unconformable relations are difficult of detection. But as Cross long ago stated:[1] "The visible conformity between the Ceratops beds and Fox Hills in Converse County cannot be accepted, contrary to other evidence, as proving the former to have been deposited in the epoch next succeeding the Fox Hills."

UPPER LIMIT OF THE LANCE FORMATION

In my original paper on the Lance formation ("Ceratops beds") I stated that everywhere throughout the vast region studied it was found conformably overlain by the acknowledged "yellow" Fort Union, adding that "of the many workers who have observed the field relations at hundreds of points, not one, so far as known to the writer, has recorded the presence of unconformity between them." Field work during the past two seasons has confirmed this statement in every particular, and there is yet to be observed a single locality at which unconformable relations have been even suspected. Hence it seems to have been demonstrated that sedimentation from one to the other was continuous and uninterrupted.

At the time the original paper was published it was thought that the Lance formation and the acknowledged Fort Union (the lower and upper members of the Fort Union as they were there called) might usually be separated on lithologic grounds, the lower being generally dark and somber-colored and the upper usually yellow. Subsequent investigation, however, has failed to confirm this, for while in individual sections, or even within limited areas, a provisional lithologic separation may often be made, when regional studies were undertaken it was found that the lithologic difference was so variable within short distances as to be wholly

[1] *U.S. Geol. Survey, Mon. 27* (1896), 236.

unreliable. For instance when a coal-bed that occurred near the top of the so-called somber-colored Lance formation was traced accurately for only a few miles it was found that the position of the dark-colored and the yellow beds varied as much as 300 feet, that is, at one point, the coal-bed might be 150 feet down in the somber-colored portion, and at another, an equal distance up in the yellow beds. It may therefore be confidently stated that the Lance formation and acknowledged Fort Union cannot be separated formationally on either structural or lithologic grounds, though in general the lower beds are on the whole prevailingly somber in color, while the upper beds are prevailingly yellow.

MAGNITUDE OF UNCONFORMITY AND BOUNDARY BETWEEN CRETACEOUS AND TERTIARY

Having demonstrated the existence of unconformable relations between the Lance formation and the underlying formations, the question naturally arises as to the magnitude of this discordance. By some it is claimed that it is merely local and is not more important than other breaks said to occur at various intervals in the Lance formation, and the doubt is expressed whether, even if the unconformity is present, any great amount of erosion is indicated.

The wide area over which its existence has now been demonstrated certainly removes it from the category of "local" happenings, and the uniformity of its occurrence beneath the Lance formation is sufficient indication of its importance over any that have been thus far even apparently indicated within the formation. Now as to its magnitude. It has been shown that in Carbon County, Wyoming, the Lance formation is not only above the full thickness of the "Laramie" (6,000 feet) but is separated from it by an unconformity that Veatch states is fully 20,000 feet, and moreover this unconformity is in the same position as regards the Laramie as that in the Denver Basin of Colorado, which, according to Cross, has involved the removal of from 12,000 to 15,000 feet of strata between the Laramie and overlying formations. It is possible that the figures given by Cross and Veatch may be too high, but even so, the unconformity is undoubtedly one of importance, and this would seem to dispose of the contention that

the Lance, Arapahoe and Denver formations may be mere "phases of the Laramie." Whether the Laramie and various post-Laramie beds were deposited and later removed throughout the Dakotas, Montana, and Wyoming, is not at present known, but certain it is that the unconformity at the base of the Lance formation represents the time interval during which in other areas they were laid down and subsequently removed in whole or in part. Therefore, in the opinion of the writer, this unconformity is an important one and must be so recognized in American geology.

Since it has been demonstrated that the Lance formation is so inseparably associated with the Fort Union—that is, without a trace of an unconformity—and is separated from the underlying formations by an unconformity of such extent, this point becomes more clearly than ever the logical point at which to draw the line between Cretaceous and Tertiary. In establishing this line the stratigraphic, lithologic, and paleobotanical criteria are believed to be more competent than any other evidence thus far brought forward.

LARGE GLACIAL BOWLDERS

GEORGE D. HUBBARD
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Mention of large glacial bowlders is not uncommon. In fact most localities glaciated have their "largest in the state." Some lie so as to reveal easily the fact that they have been transported. Others are more or less concealed, and some care is needed to determine whether the rock is really a transported mass or country rock in place.

A mass of limestone in Ohio covering about three-quarters of an acre, and in places sixteen feet or more in thickness, was mentioned by Orton in one of the older reports of Ohio geology and cited by Dana.[1] In the Alps was found a mass containing about 200,000 cubic feet of rock or enough to cover a fourth of an acre twenty feet deep.[2] Sardeson[3] reports a block of limestone moved a short distance whose width was over 100 feet, thickness several feet, and length unknown. Limestone bowlders, often large masses, are quite common in parts of Illinois, specifically in western Livingston County, in northern McLean, and in parts of Champaign, Ford, and Vermilion counties. Following is a detailed description of several masses or "pockets" of this rock which have been studied.

On the south side of the Champaign-Ford county line one and one-half miles east of the northwest corner of Ludlow township are the remains of a large "pocket." H. H. Atwood of Paxton who owns the farm says several loads of the rock have been drawn away for building purposes, but enough remains to mark the place distinctly.

Near Saybrook, McLean County, are a number of localities where limestone is found at the surface. On the farm of Mr. Riggs,

[1] J. D. Dana, *Manual of Geology*, 5th ed. (1895), 960.

[2] *Ibid.*, 248.

[3] *Jour. Geol.* (1905), XIII, 351–57.

one mile north and one and one-half miles west of Saybrook, lime was burned forty or fifty years ago. A small kiln was built and operated several years with rock from this deposit. A half-mile east of this kiln, past the schoolhouse, another "pocket" was opened and several loads drawn some thirty-five years ago. At present but few know of these limestone pits, for they have been entirely dug out and the holes are plowed over. Portions of the kilns and fragments of waste alone remain.

Two miles north and one mile west from Saybrook are a number of slabs resembling flagging. These are quite numerous on one farm. On a farm ten miles west of Saybrook lime was burned for the local market, but at present the rock is apparently exhausted. In this locality, a good many loads for foundations and well curbs have also been drawn away. According to a boring for Mr. H. Cheney of Saybrook, bed rock was struck here at a depth of 236 feet. It is recorded that a five-foot limestone bowlder was struck in a gravel bed at a depth of 150 feet. A well digger here in conversation said that in digging wells he frequently encountered limestone bowlders of various sizes, and noted several localities where the bowlder weighed from ten to twenty tons. A number of wells in the vicinity have been walled with the rock taken out in digging, supplemented with more found near by. "In fact," he says, "there is lots of limestone scattered all over the country." No bed rock, however, has ever been found about Saybrook except at considerable depths as in the well cited, 236 feet.[1] With such thickness of drift as this, these masses of limestone cannot be in place.

The largest drift mass of limestone is in Livingston County, about a mile and a half southwest of Fairbury, where Dr. Brewer has been taking out a great deal of limestone. The mass is along a small stream where the water divides, flowing around a little island. On the north bank of the south division and on both banks of the north division, rock is found; but on the extreme south bank no rock is known, nor is rock struck in any wells on the south side of the stream. Along the stream on the north side *for*

[1] Frank Leverett, *U.S.G.S. Mon. 38*, 695, reports a boring for coal here reaching rock at 247 feet.

a half-mile or more, and back from the stream a half-mile, all wells strike rock at some twelve to sixteen feet. Below the rock at the quarry is clay, a soft sticky yellow body, called by the quarrymen "soapstone." Examination showed it to be glacial drift. No large pieces of rock can be obtained in the quarry, for the whole mass is shattered. The pieces vary in size from ten or fifteen to two hundred and fifty pounds, rarely larger than can be handled by one man. At the quarry the rock is from ten to fifteen feet thick, and two or three nearby wells are reported passing through it, one finding sixteen feet of rock.

The rock seems to be almost exactly horizontal in the quarry, and it is struck at quite uniform depths in the neighboring wells. Inquiry for this stratum in the coal shafts, two in number, at Fairbury, failed to reveal its presence. One about a mile distant encountered a piece of rock at a depth of forty feet, but below it was more clay. The other about one and one-quarter miles distant found no rock for at least ninety feet.

At McDowell a little quarry is operated in rock which has almost precisely the same characters as the one at Fairbury, but it is of less extent—ten or twelve feet thick, shattered and local. West and south of McDowell about two miles from Ocoya there are two or three little quarries opened. One near a little stream is operated by two men who have taken out over a hundred cords of rock in a single summer. The rock is eighteen feet thick at a maximum, but in places only five or six feet thick. Some parts of it are shelly or shattered, but toward the bottom, this mass is firmer than any other yet considered. Sometimes pieces twelve to sixteen inches thick and six to eight feet long are removed, but no blasting is done. The near proximity to the stream caused some trouble with water seepage, so a sumpf was dug through the rock and a pump put in. A crowbar was thrust down easily in the bottom of this sumpf two or three feet. The quarrymen say the substratum is "soapstone of variable character," but it seems to be a well-packed, blue, pebbly clay with a greasy feel. That it is not one of the soft argillaceous layers of the Coal Measure rocks is shown by its pebbles. The edge of the rock is known in two directions. The edge along the stream is slanting, the other,

nearly at right angles thereto and on the east end of the quarry, is perpendicular and very regular. Rock is struck in but one well in the vicinity. Rock has been taken out from similar, though smaller local pockets, in two other localities within 80 rods.

The county surveyor of Livingston County says there are a good many local deposits along the Vermilion River, slabs, bowlders, and irregular pieces, but it is not continuous, and the layers are variously tilted.

Usually these large masses are along morainal ridges. Sometimes they are found along stream beds where they have been exposed by erosion. They cover areas varying from a few rods to over a hundred acres in extent, and differ in thickness from six or eight feet to eighteen or twenty feet. They are always in a shattered condition; often very much broken up, but sometines requiring some blasting to get out the rock. What seems the most surprising thing is that there is rarely much dip. The bedding in all the larger masses is almost horizontal. During early days when transportation was expensive, these masses of limestone were much used by the settlers, who made lime from some of them, and from others drew building material. The rock was more workable, and hence more desirable, than the granite bowlders.

Their presence in the drift, and their distribution mostly in the large recessional moraines, seems to point to a glacial origin for them. Since most if not all the masses mentioned are of Carboniferous rock, as shown by their fossils, the sources could not have been more than fifty to seventy-five miles north, for beyond that limit there is no Carboniferous rock, from which they could have come. While no specific places have been found from which it is thought these large bowlders were plucked, it is believed that they may have come readily from the bluffs of a valley, or from hills a moderate distance to the north.

REVIEWS

Iron Ores, Fuels and Fluxes of the Birmingham District, Alabama. By ERNEST F. BURCHARD AND CHARLES BUTTS. With Chapters on the "Origin of the Ores," by EDWIN C. ECKEL. Bull. U.S. Geol. Surv. No. 400. Pp. 204.

The Birmingham District, as here considered, extends as a long, narrow belt, about seventy-five miles in length by ten in width. The iron ores of the district lie in the broad, anticlinal Birmingham Valley which is structurally a part of the Appalachian Valley. An outline of the geology of the district shows rocks belonging to all the periods from the Cambrian to the Pennsylvanian, with unconformities separating all the systems except the Cambrian and the Ordovician, where the transition is within the Knox Dolomite, which here attains a thickness of 3,300 feet. An unconformity is found within the Ordovician. Within the area are extensive deposits of red hematite and brown ore, and important beds of coking coal and fluxing limestones.

The red hematite or Clinton ore is found in the Clinton or Rockwood formation which, in Alabama, consists of lenticular beds of sandstone and shale with four well-marked ore horizons. The ores occur in lenticular beds analogous to strata, interbedded with limestone, sandstone, and shale. Three opposing theories have been advanced to account for the origin of the Clinton ores: (1) original deposition; (2) residual enrichment by weathering; (3) replacement by percolating waters. Mr. Eckels shows that both the second and third theories are untenable, and that observations support the theory of primary sedimentary deposition.

The brown ores or ores of the hydrous iron oxides belong to a type common in southeastern United States, occurring as irregular masses associated with residual clays, and underlain by limestones of Cambrian and Cambro-Ordovician age. Mr. Eckel points out very forcibly that the decay of a limestone carrying disseminated iron material would not of itself yield such a deposit of ore, but that some factor must be found whereby the iron is concentrated. In his opinion, this concentration usually took place in the limestone itself.

The coke used in the blast furnaces of the district is made from coal mined in the Warrior coal field which lies to the northwest of the valley.

E. R. L.

Annual Report of the Geological Survey of Western Australia for the Year 1909. By A. GIBB MAITLAND, Government Geologist. Pp. 32, maps 4, and figs. 3.

The report contains a summary of the work done and the results obtained by each of the fifteen officers employed by the survey. Three bulletins were issued by the survey during the year 1909: Bull. 33, "Geological Investigation in the Country Lying between 21 deg. 30 min. and 25 deg. 30 min. S. Lat. and 113 deg. 30 min. and 118 deg. 30 min. E. Long., Embracing Parts of the Gascoyne, Ashburton, and West Pilbara Goldfields"; Bull. 35, "Geological Report upon the Gold and Copper Deposits of the Philips River Goldfield"; Bull. 37, "The Geological Features of the Country Lying along the Route of the Proposed Transcontinental Railway in Western Australia."

E. R. L.

"The Dakota-Permian Contact in Kansas." By F. C. GREENE. *Kansas University Science Bulletin*, Vol. V, No. 1 (October, 1909), pp. 1–8.

The paper presents a summary of the relations of the Permian and the Cretaceous in Kansas, north of the Smoky Hill River.

E. R. L.

Annual Report on the Mineral Production of Virginia during the Calendar Year 1908. Virginia Geological Survey Bull. No. I-A. By THOMAS LEONARD WATSON. Pp. 138.

Virginia possesses an abundance and variety of mineral materials, about forty varieties of which are now exploited, many of them on a large scale. A table of the mineral production in 1908 shows a total value of nearly $18,000,000, of which iron makes up over $6,000,000. Under the heading Preliminary Generalities, the author presents a brief and interesting review of the physiography and general geology of the state, including several generalized sections from various parts of the state. The parts devoted to the various mineral deposits are chiefly descriptive and statistical. A valuable feature of the report is a series of maps showing the distribution in the state of a number of the most important of the mineral deposits.

E. R. L.

Annual Report of the State Geologist, Geological Survey of New Jersey, 1909. By HENRY B. KÜMMEL, State Geologist. Pp. 123.

Besides the administrative report this volume contains the following papers: "Report upon the Development of the Passaic Watershed by Small Storage Reservoirs," by C. C. Vermeule; "Records of Wells in New Jersey, 1905–9," by Henry B. Kümmel and Howard M. Poland; "Notes on the Mineral Industry," by Henry B. Kümmel.

E. R. L.

"A Proposed Classification of Petroleum and Natural Gas Fields Based on Structure." By FREDERICK G. CLAPP. *Economic Geology*, Vol. V, No. 6 (September, 1910), pp. 503–21.

The classification proposed by the author of this paper is based on the "anticlinal" or "structural" theory, which is called into use to explain the segregation of oil, water, and gas from a primary disseminated condition. Depending on the structures which have segregated and localized the pools, seven classes of oil and gas accumulations have been distinguished by the author: I, Where anticlinal and synclinal structure exists; II, Domes or quaquaversal structures; III, Sealed faults; IV, Oil and gas sealed in by asphaltic deposits; V, Contact of sedimentary and crystalline rocks; VI, Joint cracks; VII, Surrounding volcanic vents. Class I embraces most of the known oil fields and is subdivided into five subclasses to distinguish the various relations of the pools with anticlines and synclines.

E. R. L.

"Outline Introduction to the Mineral Resources of Tennessee." Extract (A) from Bulletin No. 2, *Preliminary Papers on the Mineral Resources of Tennessee, State Geological Survey*. By GEORGE H. ASHLEY, State Geologist. Pp. 65.

This pamphlet contains a brief survey of the surface features of the state, the geological formations, and the geological history; and a list of the minerals of the state with a brief notice of their occurrence, use, etc. Bulletin No. 2, of which this is the first part to be published, is the first scientific publication of the newly established state survey, and is not intended as an original contribution but as a brief statement of facts already published, and is designed to meet the demand for immediate information on the mineral resources of the state.

E. R. L.

Summary Report of the Geological Survey Branch of the Department of Mines, Canada, for the Calendar Year 1909. By R. W. Brock, Director. Pp. 307.

Besides the administrative report of the director of the survey, there is included in this volume a short summary report by each of the geologists and officers of the survey, of the work carried out during the year. Almost all of the work at present being undertaken is along economic lines.

E. R. L.

"The Tectonic Lines of the Northern Part of the North American Cordillera." By W. Joerg. *Bull. Am. Geog. Soc.*, XLII (1910), 161–79. With map.

This paper pictures the tectonic lines of the North American Cordillera from the 40th parallel to Bering Sea. Though the author has based his work in part upon the reports of the geological surveys of the United States and Canada, he has confessedly followed Suess, in the main, both in subject-matter and in mode of treatment. The chief purpose of this paper is to consider in their larger relations the individual ranges and groups of ranges which go to make up this complex system. The interrelations of these mountain chains are discussed in a condensed synoptical form. The axes of the many separate, individual ranges are located on the map by heavy black tectonic lines which show graphically the distribution and direction of deformative movements. A prominent place is given to the mountain systems of Alaska.

In conclusion the author suggests the subdivision of the North American Cordillera from Bering Sea to the Isthmus of Tehuantepec into three major divisions: (1) Northern Cordillera, or Alaskides; (2) Central Cordillera; (3) Southern Cordillera, or Lower California and the Mexican Highland.

The boundary between the first and second divisions would be the zone of coalescence near the Alaskan boundary, that between the second and third the depression along Salton Sink, the Gila, and the Rio Grande. The decided Asiatic structure of the Alaskides is the reason given for recognizing them as an independent major subdivision of the Cordillera.

R. T. C.

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JULY-AUGUST, 1911

SAMUEL CALVIN

H. FOSTER BAIN

Samuel Calvin, who died at Iowa City, Iowa, April 17, 1911, was born in Wigtonshire, Scotland, February 2, 1840. He passed the first eleven years of his life in the little town of Wigton, living the simple, hardy life common in Scotch families of moderate means. As a boy, after school hours, he often paused at the edge of the cliff to look down upon Wigton Bay in which lay ships and schooners from all parts of the world. At that period trade between America and the various little ports on Solway Firth was active, and the longing for travel, common to all boys, was greatly stimulated in young Calvin by the sight of the vessels that came and went. Among his school companions was James Wilson, now Secretary of Agriculture, and a friendship was there formed that continued through life. The Calvin and Wilson families both emigrated to the United States in 1851, the Calvins going direct to Iowa and the Wilsons following after a short sojourn in Connecticut. Thomas Calvin, the father of Samuel Calvin, took up land south of Manchester, Iowa. At that time neighbors were few and far between in eastern Iowa. The first residents came from Indiana and, being accustomed to a wooded country, feared to venture upon the open prairie. They accordingly settled near the streams on what proved to be the poorer land. The Calvins and their associates, evidently thinking that having ventured so much in coming from Scotland they might as well venture more and save themselves

the work of clearing off timber, chose prairie land. It thus happened that from early boyhood Samuel Calvin was familiar with the great granite bowlders that mark the fertile prairies covered by the Iowan drift. Between farm work, school, and the usual country sports, his time was fully occupied until about 1861, when he entered Lenox College, at Hopkinton, near by. Lenox College, was, and is, an excellent example of the small denominational colleges that the pioneers of the Middle West founded so prolifically and supported with so much sacrifice. Without the equipment of a present-day university, or a staff of world-famous professors, it was still an excellent place for a young man desirous of getting at the fundamentals of the simple college curriculum of a half-century ago. Here Calvin remained and studied until near the close of the great Civil War, when, in company with most of the instructors and students who had not already gone to the front, he enlisted in 1864 in one of the Iowa regiments. Fortunately the war was nearly over. His military service was therefore neither long nor was it distinguished, in the sense of taking him into great battles. For the most part it was a period of dull routine, of guard duty and of marching, of occasional small skirmishes with the enemy, and a continual private skirmish for acceptable food and some comfort. He learned the rudiments of a soldier's life and the routine of camping—the latter much the more valuable to him.

At the close of the war, Calvin, with many others no longer young, went back to college to finish his studies. The college, however, had been practically wrecked. The call for men had taken both instructors and students, and while the buildings were still there, the life of the institution had been nearly broken up. After the ensuing reorganization Calvin found himself in the ranks of the instructors rather than among the students, and the interrupted college course was only completed as a result of much hard private study.

At Lenox College, among other members of the new faculty, was Thomas H. Macbride, a graduate of Monmouth College, and a man who had had the advantage, then unusual for teachers in small western colleges, of study at the University of Bonn. Macbride's interests centered in botany, and Calvin, while broadly

concerned with the whole of natural history, was already beginning to specialize in paleontology and geology. The two men became intimate friends and close companions. Together they explored the neighborhood and later, in the long vacations, the more distant parts of Iowa. With team, covered wagon, and simple camp outfit, trips were made as far west as the Missouri River, and collections of various sorts were brought back to enrich museum and classroom instruction. In the course of this work Calvin came into contact with C. A. White, at first state geologist and later professor in the State University at Iowa City. When White went East Calvin succeeded him at the university, and when the Iowa Geological Survey was re-established in 1892, he also followed him in the position of state geologist. The change to Iowa City, which took place in 1874, was an agreeable one, since the university, having larger resources, offered a larger opportunity for work; and for work Calvin always was greedy. The State University of Iowa in 1874 was not a large institution and the professors found plenty to do. Calvin occupied what has been aptly described as the "settee rather than chair" of natural history, and, as he once whimsically phrased it, he was ever after "shedding professorships." As rapidly as funds would permit he divided the work and called other men to him. Among the first was Macbride, then Nutting, and others in succession until in the closing years of his work it was not only possible for him to confine his work to geology, but to have the aid of an able corps of assistants in that. His work in the other sciences, however, was more than time-serving. His interest in animal morphology was especially keen, and in organizing and conducting zoölogical explorations he did work of real value. The results of the Bahama expedition, which brought back such unheard-of wealth of specimens of living crinoids, were due in no small part to him.

As a geologist Calvin's name and fame are principally bound up with that of the Iowa Geological Survey, which, except for a brief interim, he directed from the day of its organization, in 1892, to the day of his death. As a former member of the staff of this Survey I may be over-partial, but it is none the less my conviction that, considering time, place, and means, the Iowa Survey is and has

been one of the best-conducted institutions of its kind in America. It serves the people and the state of Iowa well, meeting their peculiar needs. In other states different methods are necessary, as they will become in time in Iowa.

The Iowa Survey owes much to Calvin. It also owes a not-to-be-forgotten debt to Charles R. Keyes, the principal assistant at the time the Survey was organized and through the period when plans were being formulated. In brief the Survey has served two main purposes: (1) It has furnished handbooks, consisting of maps and reports on the geology of the individual counties, written in simple language adapted to the understanding of students and intelligent laymen; (2) scientific and technical reports have been issued as occasion offered, covering all phases of the natural history of the state and the economic development of its resources. According to the report for the year ending December 31, 1909, all but nine counties had been surveyed and reports prepared and issued. More detailed surveys, based on topographic maps made in co-operation with the United States Geological Survey, had already been begun in areas of especial economic importance, and, as conditions permit, this system of more refined mapping will doubtless be extended over the state. In the meantime the county reports serve extremely useful purposes and afford a sure basis for broad general studies. The special reports on scientific and economic subjects have been numerous and valuable, as is attested by the list of publications of the Survey. The water, the coal, clay, stone, lead, zinc, gypsum, and minor mineral resources have all been studied by specialists, and information essential to their economical development set forth. The mineral industry has responded to the stimulus and the total value of the mineral output of the state is now many times what it was when the Survey was organized. Iowa is primarily an agricultural state and its mineral resources are relatively small; the educational phases of the Survey work have therefore always, and properly, been emphasized. On the narrow material basis, however, the Survey has made good return for the support of the state and it is deservedly popular. As an administrator, therefore, Calvin's work shows him to have been successful.

In scientific research, Calvin's personal interest lay mainly in paleontology and, in later years, in the study of the Pleistocene deposits. Aside from contributions to the paleontology of the Paleozoic invertebrates, Calvin will probably be best remembered for the discovery of the fauna of fish remains in the Devonian beds near Iowa City, and for his studies of the vertebrate remains of the Aftonian deposits. The fish remains have been investigated by C. R. Eastman, who found in them much of interest. The Aftonian bones are important because they permit fixing the age of a widely scattered series of puzzling deposits. In his last published administrative report[1] Calvin speaks of them as follows:

> This remarkable interglacial fauna is not altogether new to science. The individual species, and to some extent the fauna as a whole, have for some time been known to students of paleontology. It has also been known that some of the species were at one or more times inhabitants of Iowa. But, so far as concerns Iowa, it was not known that the few discovered forms, which heretofore have been represented by isolated finds, were contemporaneous; and outside of Iowa, in territory ranging from Texas to western Nebraska, the exact age of the beds in which the remains of this assemblage of extinct mammals were found was not definitely fixed. The fauna as a whole is markedly different from that familiar to the pioneer settlers of this State, very different from that known to the pioneers in any part of America. True horses were represented by at least two species, both quite distinct from our domestic species; there were three species of elephant, one of imperial size, and there were two mastodons, making in all five great proboscidians; there was at least one species of camel, an extinct bison, a gigantic stag, and two ponderous, awkward, clumsy ground sloths. The smallest of the three elephants seems to be identical with the hairy elephant or northern mammoth of Europe and Asia; it furnishes to this unique fauna a distinctly boreal element. The two great sloths, on the other hand, contribute an element distinctly South American. As found in Iowa, the age of the fauna is definite and clear. The beds in which the remains occur belong to the Aftonian stage; these animals lived, and the beds in which their remains were buried were laid down, in an interval of comparatively mild climate between the first and second stages of Pleistocene glaciation.

The quotation illustrates at once Calvin's broad scientific interest and the singular clearness of his writings, which makes it a pleasure to readers and a fit model for beginners.

Calvin's active interest in the Pleistocene deposits dates from

[1] *Iowa Geol. Surv.*, XX, xxii.

1896. In the spring of that year he undertook to put into shape long-accumulated notes on Johnson, the county in which Iowa City is situated. It chances that two lobes of Iowan drift reach across the northern border of this county. South of these lobes are the loess hills characteristic of much of the Iowan border and, in turn, the broad loess-Kansan plains. At that time the southern boundary of the Iowan had not been traced. From the known presence of two drifts at Afton and elsewhere in southern Iowa, it had been inferred that the Iowan boundary was much farther south than now appears true. The battle for two ice-sheets has been but too recently won to encourage belief in many. Calvin, however, intimately familiar with the typical Iowan drift plane of Buchanan and Delaware counties, recognized at once that the phenomena of southern Johnson County required a new interpretation, and shortly thereafter hit upon the clue. The rest of the staff, inspired by his enthusiasm, started out like crusaders to overturn and rebuild the Pleistocene column. The field was particularly favorable since in Iowa the different drift sheets are mainly deployed rather than superimposed, and since, also, nearly the whole sequence is represented. With the kindly counsel of T. C. Chamberlin, with friendly visits from R. D. Salisbury, J. E. Todd, Albrecht Penck, Frank Leverett, and others, the work went rapidly. There were many field conferences, and the winter meetings of the Iowa Academy of Science became notable for the discussion of current Pleistocene problems. Naturally there were differences of opinion and later work has shown the need of some revision of first-stated conclusions. Out of it all, however, has come the recognition of the independence of the pre-Kansan, the thorough establishment of the Aftonian, and the concept of the Iowan ice sheet. As to the latter, especially, there has been, and still is, much difference of opinion. The Iowan drift is so peculiar, it is so local, and the phenomena are so puzzling, that some find themselves unable to accept the evidence of its existence. It is not my purpose to review the proofs. That has already been done most excellently by Calvin himself. It is sufficient to repeat here a remark made by him at the close of the first field season devoted to this study: "The Iowan ice sheet did so many queer things that

we will never blame anyone not familiar with it in the field for denying its existence; but, whatever the explanation, there is a consistent and co-ordinate set of phenomena that demands explanation, and that is best interpreted by the hypothesis of a separate Iowan ice sheet."

Aside from his work at the university and on the Iowa Survey Calvin did his full share in the general work of his chosen profession. While he was not especially interested in economic geology, his advice was sought and valued by a number of Western mining companies; he was a member of the first Conservation Conference at the White House; he served on the National Advisory Board on Fuels and Structural Materials; he was an active member and officer of numerous professional societies, including the Geological Society of America, of which he was president in 1908; he was one of the founders of the *American Geologist*, and of the Association of State Geologists; and in many other positions he made his influence felt. He was a charming writer, a popular lecturer, and a most inspiring teacher. His personal influence was strong and deep, and the thousands of students who came into contact with him are today better men and women because he lived. He left a stainless record as a man and citizen, and an inspiring example to young men of the profession.

THE EVOLUTION OF LIMESTONE AND DOLOMITE. II (*Concluded*)

EDWARD STEIDTMANN
University of Wisconsin

PART II. CALCIUM AND MAGNESIUM IN THE PRODUCTS OF METAMORPHISM

The products of metamorphism of the rocks may be classed as solids and solutes, or residuals and losses. Residuals, the materials which remain *in situ* after a rock has suffered chemical change; losses, the materials which are dissolved, transported in solution, and redeposited elsewhere. A study of the fate of calcium and magnesium in rocks subjected to metamorphism shows that there is nearly always a marked tendency for a greater percentage loss of calcium than of magnesium. Magnesium tends to remain with the residuals to a greater degree than calcium. It will be shown that in the movement and redisposition of the residuals and losses of rock alteration, and in the reworking of these products by the same processes, again and again throughout geologic time, lies the history of a progressive enrichment of the lands in calcium and their progressive depletion in magnesium. The evidence for the selective splitting off of calcium from the parent rocks in response to metamorphic processes and the accumulation of magnesium in the residuals follows.

Materials lost by the weathering of acid igneous rocks.—The weathering[1] of acid igneous rocks results in the loss of lime, magnesia, soda, potassa, and silica. The percentage loss of the various constituents approximately follows the descending order in which they are named. For purposes of comparison alumina may be regarded as constant. The ratio of calcium to magnesium lost in the weathering of an acid igneous rock can only be given in terms of tendencies. In Table V the figures for the ratio of cal-

[1] Edward Steidtmann, "A Graphic Comparison of the Alteration of Rocks by Weathering with Their Alteration by Hot Solutions," *Economic Geology*, III, 381–409.

cium to magnesium lost are based on the assumption that alumina has remained constant. The percentage loss of calcium averages higher than that of magnesium, a tendency generally characteristic of metamorphic processes.

TABLE V

WEATHERING OF ACID IGNEOUS ROCKS

Rock	Ca/Mg Fresh Rock	Ca/Mg Materials Lost	Percentage Loss		Source
			Ca	Mg	
1 Granite	2.8	3.33	3.1	31	Watson, *Granites of Georgia*, 318
2 Granite	4.9	7.6	98	64	*Ibid.*, 315
3 Granite	2.3	5.2	88	41	*Ibid.*, 321
4 Granite	6.9	5	59	82	*Ibid.*, 320
5 Granite	3.4	4.6	43	32	*Ibid.*, 309
6 Granite	5	2.3	27	59	*Ibid.*, 312
7 Granite	5	5.2	84	83	*Ibid.*, 312
8 Granite	3.8	3	74	96	*Ibid.*, 327
9 Granite	3.9	4.3	78	70	*Ibid.*, 327
10 Granite	2.1	2.58	77	65	*Ibid.*, 325
11 Granite	3.3	4.8	80	54	Average Georgia
12 Granite	1.3	no magnesium lost	23	0	Merrill, *Rocks and Rock Weathering* (Dist. of Columbia), 207
13 Granite	1.3	no magnesium lost	21	0	*Ibid.*
14 Phonolite	3.3	12	17	5	*Ibid.* (Bohemia), 198
15 Andesite	3.4	9.5	77	28	*Ibid.* (Grenada), 208
16 Syenite	1.9	1.7	67	78	Clarke, *U.S.G.S. Bull. 330*, 412
17 Gneiss	4.2	....	100	76	*Ibid.*
Average	3.45	+4.12	59.7	50	

Materials lost by the weathering of basic igneous rocks.—In the weathering of basic igneous rocks, the percentage losses of calcium and magnesium average about even, in Table VI. The ratio of calcium to magnesium lost varies between wide margins, from one to infinity. The materials selected for analyses may have unequaled value in the problem.

Materials lost by the weathering of an average igneous rock.—The ratio of calcium to magnesium in an average igneous rock (Clarke) is about 1.37. The ratio of calcium to magnesium lost by its weathering, calculated on the basis of average calcium and magnesium decrements, is about 1.85.

TABLE VI

WEATHERING OF BASIC IGNEOUS ROCKS

Rock	Ca/Mg Fresh Rock	Ca/Mg Materials Lost	Percentage Loss		Source
			Ca	Mg	
1 Diabase......	2.2	4.1	25	9.5	Merrill, *Rocks and Rock Weathering* (Medford, Mass.), 218
2 Diabase......	1.3	1.57	83	61	*Ibid.* (Spanish Guiana), 222
3 Basalt........	1.0	.51	47	96	*Ibid.* (Crouzet, France), 223
4 Basalt........	1.2	1.4	84	74	*Ibid.* (Kammer Bull.), 222
5 Diabase......	.6	.6	98.7	98.2	Merrill, *Am. Geol.*, XXII, 93
6 Diabase......	.64	.6	98.6	98.8	*Ibid.*, 95
7 Diorite.......	1.84	1.85	97.3	97.17	Merrill, *Rocks and Rock Weathering*, 225
8 Augite diorite.	1.07	3.13	59	76	Morozewicz, *Zeit. Kryst. Min.*, CXXXIX, 612
9 Diabase......	1.08	2.13	84	42	P. Holland and Dickinson, *Proc. Liverpool Geol. Soc.*, VII, 108
10 Boulder.......	.10	infinity	17.5	00	*Helen Mine, Michipicoten* (unpub. monograph)
11 Gabbro.......	2.92	1.25	8.9	6	*Gabbro, Allen Junction, Minn.* (unpub. monograph)
12 Diabase.....	1.25	1.35	92	82	*Dike, Penokee-Gogebic* (unpub. monograph)
Average.......	1.27	1.62	66.3	61.5	

TABLE VII

WEATHERING OF LIMESTONE

Rock	Ca/Mg Fresh Rock	Ca/Mg Altered Rock	Source
Carboniferous limestone.............	148	14.9	*Ann. Geol. Rept. Arkansas* (1890), 179
Average of three analyses............	1.4	.23	*Bull. 7, Va. Geol. Surv.*, 97
Knox..............	1.6	.01	Russell, *Bull. 52, U.S.G.S.*, 25
Galena.............	1.5	1.2	*Bull. 14, Wis. Geol. Surv.*, 15–16
Galena.............	1.5	.66	*Ibid.*
Galena.............	1.5	.64	*Ibid.*
Trias, France........	17.2	2.38	Hilterman, *Die Verwitterungs-Produkte von Gesteinen der Trias Formation*, Frankens. *Inaugural Dissertation*, Erlangen, 1889
Plattenkalk.........	66.0	1.82	F. W. Pfaff, "Ueber Dolomit und seine Erstellung," *Neues Jahrb.*, XXIII, 538
Krebscheeren Kalk...	61.0	1.67	*Ibid.*, 539
Average..........	26.5	2.61	

Materials lost by the weathering of limestones.—In the present stage of earth evolution, the principal contribution of calcium and magnesium from the weathering of the sediments probably comes from limestones. A compilation of the calcium magnesium ratio of several fresh and weathered limestones seems to indicate that the percentage loss of calcium is somewhat higher than that of magnesium and that the amount of calcium given off by the weathering of limestone greatly exceeds magnesium (Table VII).

Résumé of weathering.—It follows from the facts stated that the weathering of igneous rocks and sediments results in the loss of more calcium than magnesium and that in general the percentage loss of calcium is greater than that of magnesium.

Materials lost by dynamic metamorphism.—The dynamic metamorphism of sediments as well as igneous rocks seems to bring about certain definite chemical changes. It is difficult, however, to measure these changes since it is uncertain whether any of the elements are stable in any given case. All that can be done in the problem of determining the relative stability of lime and magnesium under dynamic condition is to compare the magnesium and calcium ratios in the unaltered materials with the calcium magnesium ratios in their metamorphosed equivalents, as shown by Table IX. Secondly, to compare the importance of calcium and magnesium in the minerals of the unaltered and metamorphosed rocks. Table IX appears to indicate that the ratios of calcium to magnesium are lower in the metamorphosed phases than in the unaltered; that is, the percentage of lime lost by dynamic metamorphism appears to be higher than that of magnesium. Concordant with this apparent chemical change is the fact that the minerals which are developed under conditions of dynamic metamorphism are predominantly magnesium and potassium bearing, rather than calcium bearing, such as the micas, chlorites, and amphiboles of Table VIII. It appears that magnesium is better adapted to dynamic condition than calcium. A selective removal of calcium from the zone of anamorphism to the zone of katamorphism and ultimately to the ocean seems to be a logical sequence.

TABLE VIII

THE PERCENTAGES OF CALCIUM AND MAGNESIUM IN CALCIUM- AND MAGNESIUM-BEARING MINERALS, CHARACTERISTIC OF DYNAMIC METAMORPHISM

Mineral	Ca	Mg	
Actinolite	9.5	13.5	Variable
Anthophyllite	0.20	28.69	Variable
Augite	11.4	8.6	Variable
Biotite	.....	14.3	Variable
Chlorite	.....	20.0	Variable
Cordierite	.....	6.1	
Hornblende	8.7	8.64	
Serpentine	.....	25.8	
Spinel	.....	11.5	
Scapolite	9.2	.....	
Tourmaline	1.14	8.9	Variable
Tremolite	9.7	14.9	Variable
Vesuvianite	25.4	1.57	Variable
Wollastonite	34.6	.....	
Zoisite	17.6	.....	

TABLE IX

DYNAMIC METAMORPHISM

Rock	Ca/Mg Original Rock	Ca/Mg Altered Rock	
Average of 12 clays and soils	1.5	....	Clarke, *Bull. 168, U.S.G.S.*, 1900, p. 296
Average of 78 shales	....	1.1	Clarke, *Bull. 330, U.S.G.S.*, 1908, p. 27
Average of 9 slates of Vermont	....	.25	Van Hise, *Mon. 47, U.S.G.S.*, 1904, p. 895
Dolomite	1.5	.03	*Mon. 46, U.S.G.S.* Altered to talc schist, pp. 215–222
Average	1.5	.66	
Gabbro	.95	.44	*Bull. 62, U.S.G.S.*, p. 76
Gabbro	.95	.10	*Bull. 62, U.S.G.S.*, p. 76. Altered more than preceding case
Greenstone	1.19	1.05	*Bull. 62, U.S.G.S.*, p. 91
Gabbro diorite	1.45	.89	*Bull. 62, U.S.G.S.*, p. 89
Average	1.13	.62	

Materials lost by contact metamorphism.—Contact metamorphism of the sediments tends to develop minerals of complex constitution and high specific gravity. The materials in excess of the requirements for the development of adapted minerals tend to be removed, and in part may reach the sea. The relative

instability of calcium at contacts as compared with magnesium is suggested by the tendency toward increase in the magnesium content of altered sediments, as compared with their unaltered equivalents. See Tables X, XI, XII. The averages of the tables are misleading since they do not represent the tendency of the majority of cases.

TABLE X

CONTACT METAMORPHISM OF SLATES BY ACID INTRUSIVES

Rock	Ca/Mg Fresh Rock	Ca/Mg Altered Rock	
Chloritic phyllite	0.13	0.22	Altered by granite (*Neues Jahrb.*, 1897, p. 156)
Slate	0.18	0.05	Altered by hornblende granite 50′ from contact (Hawes, *Am. Jour. Sc.*, Mt. Willard, N.H.)
Slate	0.18	0.14	Ditto, 15′ from the contact
Slate	0.18	2.3	Ditto, 1′ from the contact
Slate	0.18	2.1	Ditto, at contact
Yaqui Gulch	0.39	0.87	Contact with quartz diorite (*Bull. 150, U.S.G.S.*)
Morenci shales	0.82	0.55	Contact with porphyry (*Bull. 229, U.S.G.S.*, p. 348)
Composite	0.62	0.38	Of 6 slates by acid intrusives
Average	0.33	0.37	

TABLE XI

CONTACT METAMORPHISM OF SLATES BY BASIC INTRUSIVES

Rock	Ca/Mg Fresh Rock	Ca/Mg Altered Rock	
Composite	.88	.36	8 adinoles altered by diabase (Roth, *Geol.*, III)
Lenneschiefer	.49	.56	Composite of 3 slates altered by diabase (*ibid.*)
Lenneschiefer	.55	.30	*Ibid.*, 147
Slates	.09	.47	Composite of 3 slates altered by dolerite (*Crystal Falls, Mon. 36, U.S.G.S.*)
Slates	.19	.32	Clausthal altered by diabase dikes (Groddeck, *Jahrb. der königlich-preuss. Landesanstalt*, 1855, pp. 1–53)
Virginia	.04	.34	By gabbro intrusive (*Mon. 43, U.S.G.S.*, 170)
Carboniferous	5.1	10.	Shale by peridotite dike (*Bull. 348, U.S.G.S.*, 343)
Average	1.04	1.75	

TABLE XII

LIMESTONE CONTACT METAMORPHISM

Rock	Ca/Mg Fresh Rock	Ca/Mg Altered Rock	
Homestake..........	12.7	1.01	By andesite (Leith and Harder, "Utah: The Iron Ores of the Iron Springs," *Dist. Bull. 338, U.S.G.S.*)
White Knob.........	18.4	74.0	By acid intrusive (Kemp, "Idaho," *Eco. Geol.*, II, 1907)
Morenci............	3.98	1.03	Altered by porphyry (*Eco. Geol.*, II, 6, 1907)
Bingham...........	54	34	Altered by porphyry (*Prof. Paper 28, U.S.G.S.*)
Bingham...........	13.2	.39	Altered by porphyry (*ibid.*)
Chanarchillo........	2.5	.57	Chile, altered by greenstone (Woesta, *Ueber das Vorkommen der Chlor. Jod. Brom. Verbindungen in der Natur*, Marburg, 1870)
Slightly altered limestone............	7.4	2.3	F. D. Adams, *Jour. Geol.*, XVII (1909)
Slightly altered limestone............	7.4	1.5	*Ibid.*

Materials lost from rocks by hot solutions.—The alteration of rocks by hot solutions along fissures also shows a marked tendency toward rapid removal of lime, and a much slower rate for the removal of magnesium. In some cases calcite, epidote, and other lime-bearing minerals develop in basic igneous rocks, but often calcium is practically absent from the secondary minerals. The compilation on page 399 has been made showing the calcium and magnesium ratio of fresh and altered rocks adjacent to ore-bearing fissures.

Résumé of calcium and magnesium in the products of metamorphism.—The data on metamorphism which have been presented indicate that the percentage loss of calcium which rocks sustain through metamorphic processes tends to be higher than that of magnesium. In fact, it could be shown that the percentage of calcium lost tends to be higher than that of any other element. Exceptions are noted, of course. In view of this tendency, Salisbury's[1] estimate that the disintegration of 55,000,000 cubic miles of average igneous rock would yield the common salt of the sea, while the disruption of three or more times as much rock would be required to yield the limestones, is suggestive.

[1] R. D. Salisbury, "The Mineral Matter of the Sea," *Jour. Geol.*, XIII, 476–77.

TABLE XIII

THE CALCIUM MAGNESIUM RATIO OF FRESH ROCKS AND THEIR EQUIVALENTS ALTERED BY HOT SOLUTIONS ADJACENT TO ORE-BEARING FISSURES

Rock	Ca/Mg Fresh Rock	Ca/Mg Altered Rock	
Granite	1.06	.18	West Australia, Pilbara, Goldfield. Quoted by Lindgren, *Eco. Geol.*, I, 540
Amphibole schist	1.50	1.5	Kalgoorlie, West Australia. Quoted by Lindgren, *ibid.*, 530–44
Granite	1.50	67.	Lindgren and Ransome, "Cripple Creek," *Col. P.P. 54, U.S.G.S.*, 194
Phonolite	5.40	2.4	Ditto
Granodiorite	1.94	5.0	Lindgren, "Placer Co. Cal.," *A.I.M.E.* (1901), 586–87
Amphibole schist	.34	1.7	Ditto
Limestone	116.	17.1	Limestone altered by hot springs. Spurr, "Aspen, Colo.," *Mon. 31, U.S.G.S.*, 210
Andesite	1.64	.35	J. E. Spurr, "No. 2 Tonopah," *Nev. P.P. 42*, p. 216
	....	.67	J. E. Spurr, "No. 3 Tonopah," *ibid.*
	....	.35	J. E. Spurr, "No. 4 Tonopah," *ibid.*
	..	.54	J. E. Spurr, "No. 5 Tonopah," *ibid.*
	....	.57	J. E. Spurr, "No. 6 Tonopah," *ibid.*
	....	.28	J. E. Spurr, "No. 7 Tonopah," *ibid.*
	....	.00	J. E. Spurr, "No. 8 Tonopah," *ibid.*
Monzonite porphyry	2.1	.17	Lindgren, "Clifton-Morenci," *P.P. 43*, pp. 168–69
	....	.24	Ditto, No. 3
	....	.09	Ditto, No. 4
	....	5.1	Ditto, No. 5
Monzonite porphyry	1.4	3.2	Boutwell, "Bingham District," *P.P. 38*, p. 178
Diorite	1.4	1.03	"Willow Creek District, Idaho," *20 Ann. Rept. U.S.G.S.*, Pt. III, 211–32
Hornblende andesite	2.59	2.71	"No. 3, Hauraki Gold Fields," *Eco. Geol.*, IV (1909), 637
Hornblende dacite	2.67	−2.86	"No. 2, Hauraki Gold Fields," *ibid.*, 638
Butte granite	1.95	.62	"No. 2, Sericitized Granite," unpublished investigation, University of Wisconsin
Butte granite	1.95	.53	"No. 8, Granite Mineralized," unpublished investigation, University of Wisconsin
Butte granite	1.95	.77	"No. 9, Hard Silicified Granite," unpublished investigation, University of Wisconsin

It is obvious that if metamorphism continued until all rocks were separated into end products, the residuals remaining in place and the materials lost transported to the sea, it would result in a running down of the calcium content of the lands, and a relative increase in magnesium.

In the deep zones of high pressure and temperature, where there is only slight mobility of the residual materials, this result may be reached and perpetuated for a long time until, in the course of geologic ages, they finally become the shallow zones of low temperature and pressure. Here the residuals of metamorphic processes as well as the materials lost are forever in a state of motion in response to the movements of the atmosphere and the hydrosphere, controlled by gravity and the sun. Thus the products of metamorphism are redistributed into the sedimentary rocks, and these in turn are reworked and redistributed. In this redistribution lies the potentiality of an increase of the ratio of calcium to magnesium of the lands with geologic time.

Has sedimentation increased the ratio of calcium to magnesium of the lands during geologic time?

The sedimentary rocks are derived from other sediments and from igneous rocks, ultimately they are derived from igneous rocks. Clarke's average igneous rock is generally accepted as representing the approximate composition of the primitive lithosphere. The criticism may be offered that this average is necessarily not based on a study of the volumetric importance of the various igneous rock types in the primitive lithosphere. It has also been maintained that the igneous rocks themselves are very largely derived from the fusion of sediments, which may be so but has not been proven. The recurrence of certain predominant igneous rock types at various times and places suggests that the composition of magmas has not been materially influenced in the way which one would expect from regional subfusion of sediments. It seems probable that the primitive lithosphere had a composition between rhyolite and basalt, which is expressed in Clarke's average. Approximations, not finalities, seem all that can be hoped for in this problem.

By an ingenious graphic method, W. J. Mead[1] estimates that the average igneous rock is equivalent to shales, sandstones, and limestones of Clarke's average compositions in the ratio of 80:11:9.

F. W. Clarke[2] has made a similar estimate, based on average

[1] W. J. Mead, "Redistribution of the Elements in the Formation of Sedimentary Rocks," *Jour. Geol.*, XV (1906), 238.

[2] F. W. Clarke, "Data of Geochemistry," *Bull. 330, U.S.G.S.* (1908).

chemical compositions, in which he distributes the average igneous rocks into shales, sandstones, and limestones in the ratio of 80:15:5.

An earlier estimate by Van Hise[1] divides the sedimentary rocks into 65 per cent shales, 30 per cent sandstones, and 5 per cent limestones.

A computation made by myself, using Mead's method, shows that a composite Georgia[2] granite made from Watson's analyses is nearly equivalent to a mixture of composite Georgia clay (Watson's) and average sandstone (Clarke's) in the ratio of 55:45, not enough lime and magnesia being present to be available for limestone. Another computation by myself shows that a composite basic rock made up from composites of diabase, gabbro, basalt, and peridotite in the ratio of 6:6; 6:1 is equivalent to average shale and limestone (Clarke's) in the ratio of 88:12. The upshot of all these computations and estimates seems to be that the predominant igneous rock types are equivalent to a large percentage of clastics, predominantly mud or shale, and a relatively small percentage of limestone, hence the same would be true of the primitive lithosphere, regardless of whether it was entirely rhyolite or entirely basalt.

Under the theory of the stability of oceanic and continental segments, the redistribution of the primitive lithosphere into sediments may have taken place along one or the other of two uniformitarian directions. The redistribution materials may have been deposited upon the continents and in the oceans in such proportions as to leave the composition of the lands unchanged. This might be termed "integral" redistribution, because it leaves the composition of the lands as a whole as it was before. Obviously "integral" redistribution of the redistribution materials to the *n*th power would not change the composition of the lands. But redistribution has certainly changed the composition of the lands with respect to one element at least—sodium. That the lands contain less sodium now than in the past, in consequence of leaching and the accumulation of non-sodiferous sediments on the

[1] C. R. Van Hise, "Treatise on Metamorphism," *Mon. U.S.G.S.*, XLVII (1904), 940.

[2] Watson, *Bull. No. 9-A*, *Geol. Survey of Georgia.*

lands, is clearly shown by Becker[1] in his recent contribution, "The Age of the Earth."

Instead of leaving the composition of the lands as before, redistribution might result in a selective withdrawal of certain elements from the lands and possibly the retention of others. This may be termed "selective" redistribution. Redistribution has been selective with respect to sodium, resulting in a progressive decline in the contribution of sodium from the lands to the sea. It probably has been selective with respect to potassium, causing only a slight accumulation of potassium in the sea as compared with sodium. The question is raised here whether selective redistribution may not have caused an actual progressive increase in the calcium content of the lands and a correlative progressive decrease in magnesium, which in turn may have been connected with a similar progressive change in the ratio of calcium and magnesium contributed to the sea, and of the calcium and magnesium carbonates deposited in the sea. It has been pointed out that regardless of whether the primary lithosphere was rhyolite or basalt, redistribution would result in a large proportion of clastics, predominantly mud, and a small proportion of limestone. If redistribution has been integral with respect to clastics and limestones, it would follow that the sediments exposed on the continents are predominantly clastics and subordinately limestones. This test will be applied here to the continental interiors, the continental margins, the epicontinental seas and the deep seas, so far as the progress of my studies permits.

The geologic record of the continental interiors.—The greater portion of the surface of the lands consists of sediments. Major Tillo[2] estimates that the Archaean and younger eruptives constitute only 24.3 per cent of the known area of the continents. It follows from obvious reasons that the greater part of the calcium and magnesium now being delivered to the sea by the rivers comes from the sediments exposed on the lands, and the proportions of calcium and magnesium in the rivers will be roughly proportional

[1] G. F. Becker, "The Age of the Earth," *Smithsonian Inst. Miscellaneous Collections*, LVI (1910), No. 6.

[2] Quoted from Berghaus' *Atlas der Geologie* (1892).

to the amount of calcium and magnesium in the sediments and to the relative solubility of calcium- and magnesium-bearing minerals in the sediments.

In his discussion of "The Metamorphic Cycle," C. K. Leith[1] says:

> Averages of sections made from field observations give uniformly a lower[2] percentage of shales and higher of limestones. An average of twenty-one sections from different parts of the United States shows thirty per cent of limestone. If the difference of proportion determined by the chemical[3] and field methods is a real one, as inspection of the data seems to indicate, the significant questions are raised, (1) whether there may not be a concentration of limestones on the continental areas, their complimentary shales and muds being in the deep sea, (2) whether limestone may not be concentrated in the upper, observed part of the lithosphere, because of its known inability to remain in the deep seated zones of high pressure and temperature.

That the Paleozoic sediments of the Mississippi Valley show a surprising concentration of limestones amounting to from 23.6 to 66.6 per cent of the sections averaged and a marked deficiency of shales and sandstones is brought out in an admirable study made by Miss F. W. Carter.[4] The results of this study are compiled in Table XIV.

TABLE XIV

TABLE SHOWING THE RELATIVE PROPORTIONS OF LIMESTONES, SHALES, AND SANDSTONE IN THE PALEOZOIC OF THE MISSISSIPPI

State	Limestone	Shale	Sandstone
Pennsylvania	23.6	47	25
Alabama	41.3	23	35.5
Ohio	33.2	41.4	23.6
Michigan	42.2	38.3	19.1
Indiana	39	30.3	30.6
Wisconsin	52	38.3	9.5
Minnesota	50.9	40.4	11.5
Iowa	61.1	29.1	9.7
Missouri	66.6	22.8	10.4
Oklahoma	31.7	52.2	16.7
Colorado—eastern	27.5	4.8	57.6
Colorado—central	57	20.9	21.9

[1] C. K. Leith, "The Metamorphic Cycle," *Jour. Geol.*, XV (1907), 304.

[2] Lower than the percentage gotten by distributing an average igneous rock into average sediments.

[3] The chemical method of W. J. Mead (*op. cit.*).

[4] Unpublished thesis (1910), University of Wisconsin.

The composition of the limestones of the Paleozoic of the Mississippi Valley averages that of magnesian limestones, with a lime percentage higher than that of a normal dolomite.

The unconformities in the Paleozoic of the Mississippi Valley represent the removal or lack of deposition of both limestones and clastics, mostly clastics, as follows from the compilation below, also made by Miss Carter (Table XV). Both sedimentation and erosion seem to have worked hand in hand toward the concentration of limestones.

TABLE XV

Table of Unconformities in the Paleozoic of the Mississippi Valley

Location	Extent	Kind of Rock Eroded	Amount Eroded	Summary
First base of St. Peter sandstone	Widespread	Limestone L. magnesian	Less than one-half thickness	
Second base Maquoketa shale	Widespread	Galena limestone	Negligible	
Third top of Silurian	Widespread	Salina and Niagara limestone	Slight	Took off limestone
Fourth top of Mississippian	Widespread	Limestones and shales	Much	
Fifth ever since Carboniferous	Widespread	Shale, sandstone, and some limestone	More than preceding combined	Took off more clastics than limestones in preceding

It seems to follow that the sediments of the Mississippi Valley were either derived from sediments already high in limestones, or else the complementary muds have been carried elsewhere, to the margins of the continents perhaps. But even granted that they were derived from sediments high in limestones, it is difficult to escape from the conclusion that ultimately redistribution was selective. Concentration of limestones on the lands began somewhere at some time. A selective withdrawal of muds from the continents began somehow, for the Paleozoic sediments of the Mississippi Valley show a proportion of limestones far in excess of the proportions gotten by redistributing either rhyolite or basalt, the two dominant magmatic differentiates.

A remarkable preponderance of limestone is also evident from

the following averages made from sections in the interior of China, described by Blackwelder in *Researches in China.*

Section	Shales	Sandstone	Limestone	Unknown
	Per cent	Per cent	Per cent	Per cent
Sinian system, Shantung, Northeastern China (Cambro-ordovician, unconformity on limestone)	14	...	86	
Shantung (Carboniferous)	71	...	29	
Shantung, Permo-Mesozoic	36	40	....	24
Shansi-Wu-Tai District. Average of Paleozoic (unconformity on limestone)	Clastics 19.5	...	80.5	
Eastern Ssi Chuan and Lower Yang Tzi Gorges. Paleozoic section (unconformity on top of upper Carboniferous limestone)	17.6	6.5	75.6	

The continent of Europe shows a similar dominance of limestones over clastics. In the southern province of sedimentation, the record is nearly continuous from the Cambrian to the Pliocene, and presents a proportion of limestones far in excess of the ratio gotten by distributing an average igneous rock into the sediments.

Another peculiarity of the sediments on the continental interiors is that they are generally less disturbed and less anamorphosed than the sediments on the margins of the continents. The marginal distribution of mountain ranges and volcanoes harmonizes with this generalization. The fact that the sediments of the continental interiors are generally less anamorphosed than those of the margins is significant in regard to their chemical denudation. Anamorphism tends to cause the decomposition of carbonates and the development of complex silicates, but the silicates are less easily dissolved, hence the relatively small amount of anamorphism of these sediments increases their importance as sources of calcium and magnesium in river waters.

Taking the lime and magnesia contents of Clarke's average sediments merely as objects of illustration, the following table suggests how important the concentration of limestone on the continents may be in changing the ratio of calcium and magnesium in the river waters from what it would be if the lands had the composition either of an average igneous rock, rhyolite or basalt.

TABLE XVI

Rock	Percentage CaO	Percentage MgO	Ratio CaO:MgO	Percentage of Average Sediment (Mead)	Percentages of Paleozoic Sediments of Missouri (Carter)
Shales (Clarke)....	3.11	2.44	1.2:1	80	22.8
Sandstone (Clarke).	5.50	1.16	4.7:1	11	10.4
Limestone (Clarke)	42.57	7.89	5.3:1	9	66.6
Average igneous rock (Clarke)....	4.79	2.39	1.4:1	..	....
Rhyolite (Osann)..	1.43	.38	3.7:1	..	....
Basalt (Osann)....	8.91	6.03	1.4:1	..	....

The ratio of lime to magnesia in the average sediment is about the same as in the average igneous rock, 1.4:1. The ratio of lime to magnesia in the Paleozoic sediments of Missouri would be about 4:1 if their composition is like that of Clarke's average sediments. The numerical values are not positive, but they point to the probability that the concentration of limestones on the continental interiors may have had a surprising effect on the lime and magnesia content of river waters, and ultimately on the chemical deposits of the sea.

The record of continental margins.—Chamberlin[1] has pointed out that the sediments which fringe the margins of the continents are characterized by a greater number of unconformities and more intense metamorphism than the sediments of the continental interiors. The imperfections of the marginal record therefore make it impossible to make a fair comparison between the limestone content of the marginal sedimentary column and that of the continental interiors. It is perhaps significant that the marginal sediments of late Tertiary and more recent times are predominantly clastic, which suggests a synchronous relation between continental expansion and the deposition of clastics.

Deposition within the 100-fathom line during continental expansion.—It is significant that in the present geologic epoch of continental expansion, the area of the epicontinental sea is limited to about 10,000,000 square miles, perhaps less than a third of what it has been during periods of great marine expansion. It is also significant that the present period of continental expansion

[1] T. C. Chamberlin, *Geology*, III, 526.

is not favorable to limestone building in epicontinental seas. The preponderance of clastics now forming on the shallows surrounding the lands is such that the sediments within the 100-fathom line are generally spoken of as consisting entirely of muds and sands, although important limestone-building areas are found around Florida, Yucatan, and on the Australian Great Barrier reef. The dominance of clastics seems to be related to climatic conditions and the rejuvenation of streams which has accompanied the rejuvenation of the lands. But shallow, epicontinental seas in times past have been important areas of limestone deposition when their expanse was greater than now.

Deposition beyond the 100-fathom line.—The area of the ocean is estimated by Murray as 143,259,300 square miles. The littoral and shallow-water zones comprise about 10,062,500 square miles, consequently the deep-sea area covers about 133,186,800 square miles. The calcareous deep-sea deposits of terrigenous origin, coral muds, and coral sands have an area of about 2,556,800 square miles or about 1.9 per cent of the deep-sea area. Of the pelagic deep-sea calcareous deposits, the globigerina ooze comprises 49,520 square miles, pteropod ooze 400,000 square miles, or a total of 49,920,000 square miles, 37 per cent of the deep-sea area. The total area of deep-sea calcareous deposits thus constitutes about 39 per cent of the deep-sea area.

The terrigenous non-calcareous muds have a total area of about 16,050,000 square miles, or about 11 per cent of the deep sea. The pelagic non-calcareous deposits have an area of about 64,670,000 square miles, approximately 48 per cent of the area of the deep sea, of which red clay represents 51,500,000 square miles and diatom ooze 10,880,000 square miles. In total, the non-calcareous deep-sea deposits cover about 59 per cent of the deep-sea area.

The content of calcium and magnesium in samples of deep-sea deposits collected by the Challenger expedition has been compiled in Table XVII.

It shows that calcium is more abundant than magnesium, the ratio of calcium to magnesium being about 13:1. The report on deep-sea deposits by the Challenger expedition concludes that the average calcium carbonate content of the deep-sea bottom is about

TABLE XVII

Deposit	Mean Depth Fathoms	Ratio of Calcium to Magnesium	Magnesium Percentage	Calcium Percentage	Approximate Percentage of Area of Ocean Bottom
Coral sand.........	176	19.2:1	1.8	34.6	coral ss and muds 1.40
Green sand........	449	30:	.64	20.0	.59
Green mud........	513			10.20	
Red mud.........	623	43:1	.64	19.55	.07
Coral mud........	740	......	....	34.2	.....
Vocanic muds.....	1,033	......	....	8.15	.42
Volcanic sands.....		16:1	.99	16.03	
Pteropod ooze.....	1,044	76:1	.42	32.2	.28
Blue mud.........	1,411	4.7:1	.56	2.71	10.00
Diatom ooze......	1,477	28:1	.32	9.17	7.60
Globigerina ooze ..	1,996	19:1	1.38	26.3	34.50
Radiolarian ooze...	2,094	2:1	1.84	4.19	1.60
Red clay.........	3,730	5:1	.70	3.48	36.00
					92.66

37 per cent, of which fully 90 per cent is derived from the remains of calcareous organisms living near the surface of the sea. However, the 37 per cent calcium carbonate at the sea bottom merely represents the difference between solution and deposition. Solution of the calcareous remains according to the Challenger report is a very important process, resulting principally from the generation of carbonic acid by the decay of the dead organisms.

It is to this fact that the decrease in calcium carbonate with depth is supposed to be due. See Tables XVII and XVIII.

TABLE XVIII

TABLE SHOWING RELATION OF $CaCO_3$ TO DEPTH OF WATER, TAKEN FROM CHALLENGER REPORT

	Average Percentage
14 cases under 500 fathoms	$CaCO_3$ 86.04
7 " from 500 to 1,000 "	$CaCO_3$ 66.86
24 " " 1,000 to 1,500 "	$CaCO_3$ 70.87
42 " " 1,500 to 2,000 "	$CaCO_3$ 69.55
68 " " 2,000 to 2,500 "	$CaCO_3$ 46.73
65 " " 2,500 to 3,000 "	$CaCO_3$ 17.36
8 " " 3,000 to 3,500 "	$CaCO_3$ .88
2 " " 3,500 to 4,000 "	$CaCO_3$ .00
1 " over 4,000 "	$CaCO_3$ trace

The calcium content of the ocean is a variable controlled by its solution and deposition in the ocean and its introduction from the lands. It is therefore barely possible that calcium is now accumulating in the sea, partly from direct chemical reasons, the calcium content of the ocean being below the saturation point, and partly because the shallow-water area, most conducive to the biochemical deposition of calcium carbonate, is relatively limited during the present epoch of continental expansion; and partly because the shallow waters bordering the continents are now considerably polluted by mud and other land débris which depreciates the shore zone as a habitat for lime-secreting organisms. Present climatic conditions also restrict the life zones favorable to shallow-water limestone deposition. Murray and Irvine[1] have concluded from experimental evidence that the calcium carbonate of the sea is probably nearly constant in quantity, since the precipitating agents of the sea probably maintain a balance between the introduction and deposition of calcium carbonate, despite the fact that the calcium carbonate content of the sea is below the saturation point. Whether or not calcium carbonate is actually accumulating in the sea seems uncertain, when the wide range of precipitating conditions controlled by the temperature, pressure, and the relative abundance of living and decaying organisms is considered. Nor would annual analyses of sea water give any clue, since it has been estimated that it would require about 680,000 years to accumulate the calcium carbonate now in the sea at the present rate of contribution from the land, a fact which in itself may be significant of the possibilities in this problem. Judging from the selective solubility of calcium carbonate with respect to depth, it seems that the widening of the epicontinental sea to approximately 30,000,000 square miles during the Carboniferous, as estimated by Chamberlin, must have given a tremendous impetus to the deposition of calcium carbonates on these extensive shallows. Here wave agitation might cause mechanical precipitation, and would minimize the carbonic acid content of the waters which might otherwise be influenced by organic decay. Evaporation would tend to cause concentration. Thus in shallow waters,

[1] *Proc. Roy. Soc. Edinburgh*, XVII (1890), 81.

calcium carbonate may become so unstable through these and other causes as to result in direct chemical precipitation as shown by the well-known case described by Willis[1] in the Everglades off the Coast of Florida and that of Lyell[2] in the mouth of the Rhone. In shallow, warm waters near the lands, the deposition of calcium carbonate through lime-secreting organisms is very much more rapid than in deep waters.

While 90 per cent of the accumulations of calcium carbonate on the floor of the present deep sea come from the skeleta of free-swimming organisms which thrived within the photobathic zone in shallow waters, the remains of both the free-swimming and benthos organisms augment the rate of accumulation. Furthermore, the chances for the preservation of skeleta are many times better in shallow water than in the deeps, as shown by the decrease in the calcium carbonate content of marine deposits with depth. In sinking through miles of water, the remains of pelagic organisms often dissolve before reaching the bottom. Not only is there a very clear dependence of abundant limestone deposition on shallows in the present seas, but from the physical evidence of ripple marks, etc., Schuchert concludes that North American Paleozoic limestones were probably all deposited in less than 300 feet of water. The food supply is another very important factor which attracts lime-secreting organisms to warm, clear, shallow seas near the continents.

The activity of the lime-secreting organisms would be further stimulated by the climatic moderation and uniformity which seem to accompany periods of oceanic expansion. The warming of the seas, consonant with oceanic expansion according to Chamberlin's hypothesis, would diminish its capacity for carbonic acid and decrease the solubility of calcium carbonate. But the shallow epicontinental sea, it seems, would be most susceptible to solar heating, hence from a combination of causes, mechanical, physical, chemical, and organic, limestone building in the shallow seas would probably be intensified in more than arithmetical ratio to the increase in the area of shallow water. The total contribution of calcium from the land would be lessened because of the decreased

[1] *Jour. Geol.*, I (1893), 512. [2] *Principles of Geology* (12 ed.), I, 426.

area of the lands. Could not a depletion of the calcium carbonate content of the sea result from intensified deposition on the submerged continents? What then? The solubility of the calcium carbonate toward the shallows from the deeps, a process now in operation as shown by the results of the Challenger expedition, would be accelerated. The selective accumulation of limestones on the continents as shown by geologic sections would be consummated.

Significance of the deposition of muds in the ocean basins.—The composition of river muds is variable, depending upon the composition of the lands over which the rivers flow. The longer the delta region of a river, in general, the smaller probably will be the amount of soluble materials in the muds. The Nile and Mississippi muds may be regarded as typical of the larger streams of the world. In an analysis of Mississippi mud[1] the ratio of lime to magnesia is 1.11:1 (Table XIX). The ratio of lime to magnesia in an analysis of Nile[2] mud is 1.82:1.

TABLE XIX

TABLE SHOWING LIME AND MAGNESIA RATIOS OF NILE AND MISSISSIPPI MUDS

	CaO Percentage	MgO Percentage	Ratio of CaO to MgO
Nile mud.	4.85	2.64	1.82
Mississippi mud.	1.83	1.64	1.11

The analyses of Nile and Mississippi muds show a relatively high content of magnesia, as compared with other sediments. It follows that if any large proportion of muds is lost from the lands through deposition in the ocean basins, it would mean a selective abstraction of magnesia from the lands, considering the quantitative importance of the muds. The ratio of suspended material to total dissolved solids in the Mississippi at Memphis, according to Dole's yearly average, is 2.3:1. Mellard Reed has estimated that the proportion of suspended to dissolved materials in the river waters of the world is 66:33, or 2:1. Approximately one-half of the dissolved material is calcium carbonate. The ratio

[1] By C. H. Stone, *Science*, XXIII (1906), 634.

[2] Analysis D., *Bull. 330, U.S.G.S.*, 429.

of suspended materials or muds to calcium carbonate is about 4.4:1, which argues for a great deficiency in muds in the sediments now forming as compared with the proportion got by distributing average igneous rock under conditions most favorable to the deposition of clastics, namely, the condition of continental expansion. This is in line with the fact that the present lands represent an accumulation of limestones. Of the muds now carried to the sea, the major portion are deposited on the continental shelves, and therefore have the potentiality of again becoming a part of the land surface. J. W. Barrell[1] estimates that from 50 to 70 per cent of the solids brought down to the sea by rivers is deposited within the 100-fathom line. But many of the large world streams, the Amazon, the Congo, Indus, Ganges, and others, have their terminations near the 100-fathom line. Amazon muds have been traced to a distance of 300 miles from the mouth. Barrell estimates that from 20 to 50 per cent of the muds from the rivers are deposited beyond the 100-fathom line, and are thus permanently withdrawn from the lands. This estimate is entirely in harmony with the deficiency of clastics in geologic sections, and with the probable withdrawal of magnesium from the lands which is registered in the decreasing magnesium content of limestones in going up the geologic time scale. But the loss of muds from the lands may have been even greater in the past, since many large streams in various latitudes have submerged channels which in some cases extend to the edge of the 100-fathom line. On the other hand, the percentage loss of muds undoubtedly was relatively much less during periods of widespread continental submergence. But during such periods, the total mud transported was very much less, owing to the smaller relief of the lands and their floral blanket resulting from the moderate, equitable climatic conditions which appear to have accompanied the expansion of the seas. During such periods, muds were accumulating on the lands, until periods of continental uplift, like the present, accelerate their transportation toward the continental margins and the deep sea.

Does the ratio of calcium to magnesium in the sea show a selective loss of magnesium from the lands with geologic time?—The ratio of calcium to magnesium in the river waters of the world, taking

[1] J. W. Barrell, *Jour. Geol.*, XIV, 346.

Clarke's data, is approximately 6:1. In the ocean, the ratio of calcium to magnesium is 0.35:1. The relative amount of calcium abstracted from sea water is evidently many times greater than that of magnesium. At the present time, a large proportion of the calcium is being deposited in the deep sea, and is thus either temporarily or permanently withdrawn from the land. A very large proportion of the calcium delivered to the sea has, however, been returned to the lands in the form of limestone deposits; in fact there seems to have been a relatively greater return of calcium carbonate to the lands than of the complementary clastics.

In view of the excess of limestone on the lands, it seems highly probable that the high magnesium content of the ocean represents a selective withdrawal of magnesium from the lands during geologic time. This may be one factor which could have caused a decline in the proportion of magnesium contributed to the sea, in the same way as the sodium contribution has declined with geologic time, because of its accumulation in the sea.

Résumé of results of sedimentation and their effect on the ratio of calcium to magnesium of the lands.—1. The marine sediments which are revealed to the geologist on the continental interiors were deposited during periods of widespread continental submergence. It is a significant fact that the sediments on the continental interiors probably represent several times as much limestone as could be gotten by redistributing an average igneous rock, or average rhyolite or basalt. The gain in limestone seems to be due mainly to a loss of the complementary shales and selective deposition of limestones on the continental interiors. The sedimentary mantle covers about three-fourths of the known area of the continents. The ratio of calcium to magnesium in the average igneous rock is about 1.37 to 1 (Clarke). The lowest ratio of calcium to magnesium in any group of limestones in Daly's[1] compilation is 2.93:1, and the maximum 56.32:1. The ratio of calcium to magnesium in Clarke's average limestone is about 5 to 1. The ratio of calcium to magnesium in the average shale (Clarke) is about 1.48 to 1; that of the average sandstone (Clarke), 5.5 to 1. The dominance of sedimentary over Archean and eruptive terranes and the high percentage of limestones over muds

[1] R. A. Daly, *Bull. Geol. Soc. of America,* XX, 153–70.

indicate a higher ratio of calcium to magnesium of the present lands than in the primitive lithosphere.

2. The marginal sediments show a tendency toward more intense anamorphism, a greater number of and more profound unconformities than those of the interior, and a dominance of clastics in those sediments which were deposited during continental expansion. More intense anamorphism[1] of the border sediments involves a selective retention of magnesium in them.

3. Marine sediments on the present continental shelves within the 100-fathom lineconsist predominantly of clastics, from 50 per cent to 70 per cent of the river-borne sediments being deposited here. This seems to afford a fair perspective of the nature of sedimentation during continental expansion.

4. Areally the calcareous deposits constitute a minority of the deep-sea deposits. The rate of accumulation of the terrigenous deep-sea muds is probably vastly greater than that of the calcareous deposits. Furthermore, a considerable portion of the calcareous deposits goes back into solution, and has therefore the potentiality of returning to the lands. The permanent withdrawal of terrigenous muds from the land areas unquestionably exceeds that of calcareous deposits. This selective withdrawal suggests one factor in the causation of the loss of muds from the continental interiors. Since muds not only tend to absorb more magnesium than calcium, but actually show a high magnesium content when compared to other sediments, it is not improbable that the permanent loss of muds from the continents also involves a selective and permanent loss of magnesium.

5. The selective retention of land-derived magnesium in sea water may have been an important factor in causing an increase in the ratio of calcium to magnesium of the lands.

HAS THE RATIO OF CALCIUM TO MAGNESIUM IN THE RIVER WATERS INCREASED WITH GEOLOGIC TIME?

The lands have been shown to represent a higher content of limestone than could have been gotten from the redistribution of the principal igneous rock types which are generally accepted

[1] *Ibid.*, 37, "Dynamic Metamorphism."

as approximating the composition of the primitive lithosphere. In tracing the evolution of the limestones and dolomites to chemical changes in the sea, it is found highly probable that the ratio of calcium to magnesium in the streams is higher at the present time than in the streams of the primitive lands. This will develop from the following considerations.

The influence of the terranes on the calcium magnesium ratio of underground water and streams.—Unfortunately the data on the calcium magnesium ratio of streams and underground water cannot be regarded as a satisfactory basis for correlation with the calcium magnesium ratio of the terranes over which they flow. The chances of error in water analysis and the variability of the composition of streams make a single analysis or even a group of analyses a questionable basis of correlation. The yearly average stream compositions based on daily samples gotten by the United States Geological Survey[1] for the streams of the United States east of the 100th meridian constitute a creditable exception.

Judging by the data available, it seems that underground waters and streams have a higher ratio of calcium to magnesium than the terranes through which they flow. This agrees with the fact that the metamorphism of rocks results generally in a higher percentage loss of calcium than of magnesium. From Orton's[2] figures, the average ratio of calcium to magnesium in the Niagara limestone of Ohio is 1.72. The rock waters as reported by Orton in the Niagara limestone have the following ratios of calcium to magnesium:

LOCALITY	Ca/Mg
Sidney, Ohio	4.0
Celina, Ohio	1.92
Fountain Park, Ohio	3.15
Fountain Park, Ohio	2.52
Plain City	2.55
Harrisburg	2.59

An average of 66 analyses of well waters from sandstones given in *Bull. 4*, of the University of Illinois, yields a ratio of calcium

[1] R. B. Dole, "Water Supply," *Paper 236, U.S.G.S.*

[2] Edw. Orton, *Nineteenth Ann. Rept. U.S.G.S.*, Part 10.

to magnesium of about 2.6. Twenty-four analyses of well water from dolomites gave an average calcium magnesium ratio of 2.3.

None of the crystalline terranes from which stream analyses are reported can be regarded as equivalent in composition to an average igneous rock, in which the ratio of calcium to magnesium is about 1.37 to 1.

The analyses are of unequal value. Only those of the Chippewa and Wisconsin are based on yearly averages. The calcium ratio of the others may be too high or too low. In the following table, the ratio of calcium to magnesium varies from 2.03 to 4.91.

TABLE XX

TABLE SHOWING THE CALCIUM MAGNESIUM RATIO IN STREAMS FLOWING OVER CRYSTALLINE ROCKS

River	Mg	Ca	Source
Arkansas River, Canyon, Colo	1	3.95	Clarke, *Bull. 330, U.S.G.S.*, 59
Pigeon R., Minn	1	3.14	*Ibid.*, 61
Ottawa R. Low water (*a*)	1	3.50	Daly, *Bull. Geol. Soc. Am.*, XX, 159
Ottawa R. High Water (*b*)	1	3.82	*Ibid.*
Ottawa R. mean (*a*) and (*b*)	1	3.69	*Ibid.*
Ottawa R. (St. Anne)	1	4.91	*Ibid.*
From granite terrane, average 6 analyses	1	3.20	J. Hanamann, "Bohemia," *Archiv. Natur-Landesforschung Böhmen*, IX, No. 4
From mica schist, av. 6 analyses	1	2.48	*Ibid.*, X, No. 5
Wisconsin River	1	2.03	Average of one year. Dole, *W.S. Paper, U.S.G.S.*, 236
Chippewa River	1	2.70	Average of one year. Dole, *W.S. Paper, U.S.G.S.*, 236

The following calcium magnesium ratios of streams on shales and dolomites are based on yearly averages of daily samples reported by Dole.

TABLE XXI

THE CALCIUM MAGNESIUM RATIO IN STREAMS FLOWING OVER DOLOMITE AND SHALES

River	Sample	Mg	Ca	
Fox River, Elgin, Ill.	Niagara dolomite	1	1.70	Average of 1 year
Fox River, Ottawa, Ill.	Niagara dolomite and Cincinnati shale	1	1.87	" " " "

TABLE XXI—*Continued*

River	Sample	Mg	Ca	
Kankakee, Kankakee, Ill.	Niagara dolomite	I	2.76	Average of I year
Rock, Rockford, Ill.	Dolomite and shale	I	1.80	" " " "
Rock, Sterling, Ill.	" " "	I	1.80	" " " "
White, Azalia, Ind.	" " "	I	2.65	" " " "
White, Indianapolis, Ind.	" " "	I	2.55	" " " "
Cedar, Cedar Rapids, Ia.	" " "	I	3.00	" " " "
Hudson, Hudson, N.Y.	" " "	I	5.50	" " " "
Wabash, Logansport, Ind.	" " "	I	2.34	" " " "
Wabash, Vincennes, Ind.	" " "	I	2.77	" " " "
Illinois, La Salle, Ill.	" " "	I	2.27	" " " "
Illinois, Peoria, Ill.	" " "	I	2.33	" " " "
Illinois, Kampsville, Ill.	" " "	I	2.35	" " " "
Iowa, Iowa City, Ia.	" " "	I	2.88	" " " "
Maumee, Toledo, O.	" " "	I	3.56	" " " "
Little Vermilion, Streator, Ill.	" " "	I	1.72	" " " "
Little Wabash, Carmi, Ill.	" " "	I	2.30	" " " "
Miami, Dayton, O.	" " "	I	2.45	" " " "
Cache, Mounds, Ill.	" " "	I	3.16	" " " "
Big Vermilion, Danville, Ill.	" " "	I	2.16	" " " "
Big Muddy, Murphysboro, Ill.	" " "	I	2.08	" " " "
Embarass, Charleston, Ill.	" " "	I	2.12	" " " "
Embarass, Lawrenceville, Ill.	" " "	I	2.30	" " " "
Grand, Grand Rapids, Mich.	" " "	I	2.94	" " " "
Muskingum, Zanesville, O.	" " "	I	4.52	" " " "
Sangamon, Decatur, Ill.	" " "	I	2.11	" " " "
Sangamon, Springfield, Ill.	" " "	I	2.16	" " " "
Sangamon, Chandlerville, Ill.	" " "	I	2.08	" " " "

The average calcium to magnesium ratio of these streams is between 2.5 and three. The ratio of calcium to magnesium of a normal dolomite is 1.61; that of an average shale 1.47 (Clarke). The calcium to magnesium ratio of the streams is probably higher than that of the terranes through which they flow.

An average of five water analyses on phyllite reported by Hanamann shows a ratio of calcium to magnesium equal to 2.37.

The stream waters from limestone areas show a high calcium ratio. See Table XXII.

TABLE XXII

TABLE SHOWING THE CALCIUM MAGNESIUM RATIO IN STREAMS FLOWING OVER LIMESTONE

River	Mg	Ca	Source
Thames	1	11.6	*Bull. 330, U.S.G.S.*, 75
Meuse, Liège, Belgium	1	10.8	*Ibid.*, 75
Seine at Bercy	1	46.0	*Ibid.*, 76
Loire at Orléans	1	10.7	*Ibid.*, 76
Rhone at Geneva	1	16.8	*Ibid.*, 76
Kentucky River, Frankfort	1	5.5	*Ibid.*, 66
Cumberland at Nashville	1	10.6	*Ibid.*, 66

The following table of averages suggests the influence of the terrane on the run-off.

TABLE XXIII

Terrane	No. of Analyses	Ca/Mg
Limestones	7	15
Phyllites	5	2.37 Hanamann
Crystalline	11	3.36
Dolomites and shales	29	2.91
Sandstone	66	2.6
Dolomite	24	2.3

The influence of climate on the calcium magnesium ratio of streams.—Clarke[1] has pointed out that the streams of humid, more or less forest-covered portions of North America are normally carbonate waters in which calcium is the principal base, while rivers in arid climates tend to be high in sulphates and chlorides in which calcium may or may not be the principal base. The

[1] F. W. Clarke, *Bull. 330, U.S.G.S.*, 72.

magnesium content of streams in arid climates tends to be high, as shown by the following table.

TABLE XXIV

CALCIUM MAGNESIUM RATIO IN STREAMS OF ARID COUNTRIES

Streams	Mg	Ca	Source
Sacramento R., Cal.	1	2.12	Clarke, *Bull. 330, U.S.G.S.*, 70
San Lorenzo R., Cal.	1	2.01	*Ibid.*, 70
Santa Clara R., Cal.	1	2.30	*Ibid.*, 70
Mission Creek, Cal.	1	3.83	*Ibid.*, 70
Cold Spring Creek, Cal.	1	3.01	*Ibid.*, 70
Mono Creek, Cal.	1	2.74	*Ibid.*, 70
Santa Ynez R., Gibraltar, Cal.	1	2.93	*Ibid.*, 70
Chelif R., Algeria	1	1.81	*Ibid.*, 70
Chelif R., Algeria	1	1.50	*Ibid.*, 70
Chelif R., Algeria	1	2.88	*Ibid.*, 70
Brazos R., Tex.	1	4.67	*Ibid.*, 69
Rio Grande, Tex.	1	7.20	*Ibid.*, 69
Pecos R., N.M.	1	3.72	*Ibid.*, 69
Colorado River, Yuma, Ariz.	1	3.30	*Ibid.*, 69
Gila River, Ariz.	1	3.17	*Ibid.*, 69
Salt River, Ariz.	1	2.65	*Ibid.*, 69
Colorado R., Austin, Tex.	1	3	Dole, *W.S. Paper 236, U.S.G.S.*, 56
Rio Grande, Laredo, Tex.	1	4.5	*Ibid.*, 96
Brazos, Waco, Tex.	1	6.3	*Ibid.*, 50

Where the terrane is exceptionally calcareous, however, calcium may predominate considerably. The insolubility of lime under arid conditions is illustrated by Hilgard's[1] composite soils, Table XXV.

TABLE XXV

CALCIUM MAGNESIUM RATIO IN SOILS FROM ARID AND HUMID REGIONS

Soil	Mg	Ca
Average of 466 soils from humid regions of southern part of United States	1	.57
Average of 313 soils from arid portions of United States	1	1.15

Apparently soils in arid climates contain about twice as much calcium in proportion to magnesium as those of humid climates.

Influence of the belt of cementation on the calcium magnesium ratio of underground waters.—The materials carried in solution by underground waters in the belt of cementation undergo various abstractions and additions on their way to the sea. The cements

[1] E. W. Hilgard, *Bull. No. 3, U.S. Weather Bureau* (1892), 30.

of the limestones and sandstones undoubtedly contain much more calcium than magnesium, although no estimate of their relative proportions can be given. Since the ratio of calcium to magnesium in the average sandstone (Clarke's) is 5.50 to 1, it is probable that the ratio of calcium to magnesium of the cementing materials in the sandstones is even higher.

The solutions which percolate through shales, clays, and other silicates are known to suffer an exchange of bases and other changes through the interaction of water solutions and silicates. This interaction is dependent upon the condition of chemical equilibrium between the solutions and the silicates. Kiilenberg[1] and other experimenters have shown that soils absorb more potassa and magnesia than lime and soda. The great absorption of potassa by soils and the very slight absorption of soda has been interpreted as the reason why land plants utilize potassa more largely than soda.

TABLE XXVI

RATIO OF CALCIUM TO MAGNESIUM IN THE CHLORIDE WATERS OF THE DEEP COPPER MINES OF MICHIGAN, AS COMPARED WITH THE SURFACE WATER

Deep Mine Waters	Ratio of Ca: Mg
C. and H. vertical shaft	62
Tamarack Junior (very strong)	319
C. and H., 3,000 feet	412
C. and H., 17th level	475
Tamarack, 4,300 feet	(trace of magnesium present)
Trimountain, 9th level	(trace of magnesium present)
Quincy mine (very strong)	4,300
Quincy mine	3,078
Surface water	4.75

The influence of silicates in the belt of cementation on the calcium magnesium ratio of underground waters is suggested by a comparison of the calcium magnesium ratio of the surface and deep waters of the copper mines of Lake Superior. The deep waters are probably the modified residuum left from the cycle of deposition which developed the ores and gangue minerals. The result of cementing processes has been a concentration of calcium in the solutions. Magnesium has evidently been forced out of solution by the conditions of chemical equilibrium. See Table XXVI.

[1] *Mitteil. d. Landw. Centralvereins für Schlesien*, Heft 15, p. 83, quoted by E. C. Sullivan, *Bull. 312*, *U.S.G.S.*, 16–19.

The relative absorptive power of the crustal materials for calcium and magnesium has not been adequately determined. Certain it is that many shales, slates, muds, and soils have a higher content of magnesium than of calcium. The probability that the selective withdrawal of muds from the lands to the deep sea has involved a selective loss of magnesium from the lands has been pointed out on p. 414.

The average calcium magnesium ratio of the solutions contributed to the sea.—The Mississippi[1] at New Orleans, which may be regarded as a mixture of the waters from the average Paleozoic terrane, shows a ratio of calcium to magnesium of 3.81 to 1. The average calcium to magnesium ratio of 73 streams east of 100th meridian of the United States observed daily at 94 stations for a period of one year is about 4 to 1. In Sir John Murray's well-known composition of 19 streams of the world, the calcium to magnesium ratio is 4.4 to 1. From Mellard Reade's[2] data, the ratio of calcium to magnesium in the materials of chemical denudation is 8.25 to 1. A better based figure for the average composition of the streams of the earth is that recently made by Clarke.[3] The ratio of calcium to magnesium in Clarke's average as previously cited is about 6 to 1.

While the ratio of calcium to magnesium of the solutions contributed to the sea is higher than it would be if the lands had the composition of an average igneous rock, the largest streams do not seem to show the high calcium to magnesium ratio that one would expect from the amount of limestone on the continents. However, the Mississippi is about the only large stream whose composition is accurately determined. It may be that the large amount of suspended material in rivers tends to lower the calcium ratio, since the muds, particularly of humid climates, tend to be high in magnesium. The arid nature of about one-fifth of the land area is another factor which may cause a retention of calcium by the land. If this hypothesis is correct, a compensating increase in the calcium ratio of rivers will be contemporaneous with oceanic expansion.

[1] R. B. Dole, *W.S. Paper 236, U.S.G.S.*, 117.

[2] Mellard Reade, *Chemical Denudation in Relation to Geologic Time* (1879), 1–61.

[3] F. W. Clarke, *Study of Chemical Denudation*, Smithsonian Institution, Vol. LVI (1910), No. 5, p. 8.

Conclusion: Increase of the ratio of calcium to magnesium in rivers with geologic time.—Evidence has been presented to show that the ratio of calcium to magnesium of stream water is influenced primarily by the ratio of calcium to magnesium of the terranes which they drain, being generally higher than that of the terranes.

Climate exerts a modifying influence. Aridity lowers the ratio of calcium to magnesium of the stream waters, causing a concentration of calcium in the soils, while humidity has the opposite effect. The interaction of the salts carried in solution by streams and ground waters with the land materials, particularly those high in clay, results in a greater loss of magnesium from the waters than of calcium, thus tending to increase the ratio of calcium to magnesium of the streams and ground waters.

Regardless of any theory of the origin of the earth, geologic evidence points to the igneous rocks as the primitive source of the sedimentary rocks. The streams of the primitive lithosphere, therefore, probably approached in their chemical character the present streams, flowing over crystalline rocks, subject to climatic and other modifications. Such streams have a ratio of calcium to magnesium approximating 3 to 1. The best figure given for the average calcium to magnesium ratio of the streams of the world is approximately 6 to 1. The latter figure probably should be greater, considering the abundance of limestone on the continents. Little doubt therefore remains that the proportion of calcium to magnesium in the streams is now higher than in earlier stages of the earth's history. It is also highly probable that the increase in the ratio of calcium to magnesium in the rivers has been continuous with geologic time, because of the progressive increase in this ratio in the limestones deposited during geologic time, and because of the selective deposition of limestones on the submerged continents.

STATEMENT OF HYPOTHESIS

The conclusion has been reached that dolomites develop predominantly in the sea rather than by the metamorphism of limestones after their emergence from the sea. Hence the decline in the percentage of dolomite in going up the geologic column seems

to indicate that less and less dolomite was deposited in successive periods of geologic history, thus pointing to a progressive change in the conditions of deposition. Of the four factors controlling the deposition of carbonates in the sea, viz., temperature, pressure, life processes, and chemical composition, only the last two show any probability of progressive change with time. There is no evidence for a change in the nature of life processes. There is evidence for a change in the chemical composition of the sea, specifically for an increase in the ratio of calcium to magnesium contributed to the sea from the lands, which will appear from the following considerations. The present lands contain a much larger proportion of limestones than could be gotten by redistributing a granite or basalt, generally accepted as being equivalent to the materials of the primitive lands. It is inferred from a consideration of the relation between the composition of river waters and the terranes which they drain that the present rivers have a higher ratio of calcium to magnesium than those of the primitive lands.

The accumulation of limestones on the lands of increasing calcium content, with time, seems to be related to a reworking of the land over and over again along certain selective lines. A higher percentage of calcium than of magnesium tends to be lost from all kinds of rocks when subjected to all kinds of metamorphic processes. Hence there is a continuous selective removal of calcium from the lands of the sea, as is evidenced by the fact that the ratio of calcium to magnesium of rivers tends to be higher than the ratio of calcium to magnesium of the lands which they drain. This involves a selective retention of magnesium in the clastics. The transportation and deposition of clastics is at a maximum during periods of continental expansion and at a minimum during periods of continental submergence. The clastics are therefore deposited mainly on the margins of the continents and in the deep sea. Those deposited in the deep sea are permanently lost to the lands and with them goes a selective loss of magnesium from the lands. The carbonates, calcium and magnesium, are deposited mainly in shallow epicontinental seas during periods of continental submergence, in consequence of organic

and inorganic agencies. The percentage of calcium carbonate which is deposited from the sea is higher than that of magnesium carbonate, and from field and laboratory evidence it is inferred that the proportions of the two carbonates deposited are in some direct relation to their proportions in the rivers which bring them to the sea. Hence, there is a selective return of calcium to the lands.

It is therefore inferred that the evolution of the limestones and dolomites has been in response to the gradual increment of calcium over magnesium in the solutions contributed to the sea, a tendency arising primarily from physical-chemical causes, aided or accelerated by organic processes working harmoniously with the inorganic environment.

For illustration, it may be assumed that sedimentation began during continental expansion when the lands had the composition of an average igneous rock. From the known results of metamorphic processes, it would follow that the solutions contributed to the sea had a higher calcium to magnesium ratio than the lands from which they were derived, and that the residuals had a higher proportion of magnesium to calcium than the original rocks. A part of the residuals, particularly the muds, are subject to selective transportation to the continental margin and the deep sea. Accepting the hypothesis of the permanence of oceans and the continents, those deposited in the deep sea are permanently removed from the continents. The calcium and magnesium salts interact with the materials of the ocean bottom and enter into the constitution of silicates, carbonates, and other compounds, or they may interact with other constituents in the water, and be precipitated principally as the carbonates. Magnesium would tend to interact more actively with the muds of the bottom than calcium. Calcium would tend to be more insoluble in shallow water than in the deeps, while the opposite tendency probably characterizes magnesium. Magnesium salts in general are more soluble in sea water than calcium salts. Organic precipitation, apparently only an adaptation to conditions of chemical equilibrium already existing, would be particularly effective in abstracting calcium from warm, shallow seas. The relative solubility of the materials

precipitated would depend upon conditions of equilibrium controlled mainly by temperature, concentration, the amount of carbonic acid in the air and ocean, and organic processes. As a result of the preceding selective influences, the calcium to magnesium ratio of the limestones would tend to be higher than that of the solutions contributed to the sea. However, contemporaneous with continental expansion, as at the present time, limestone deposition would be at a minimum, which might involve a concentration of calcium in the sea until more favorable conditions of precipitation arise. Limited areas of shallow water, vigorous erosion, continental climates, and other supplementary conditions make periods of continental expansion more favorable to the deposition of clastics than limestones.

Gradually the lands waste away, the ocean advances over the continents, partly in consequence of fill from the land, in part, perhaps, as a result of secular earth movements which cause a shallowing of the ocean basins. The rivers carry less and less débris to the sea, and deposit it farther and farther inland from the margin. On the submerged continental areas, covered by shallow seas, which now may be three or more times as extensive as they were during the preceding period of continental expansion, chemical and biochemical processes combine in making this an era of limestone building. From experimental and field evidence, the inference is drawn that *the ratio of calcium to magnesium in the deposited limestones is influenced primarily by their respective rate of contribution from the land, and modified by selective organic and inorganic agencies working to a common end.*

As postulated by Chamberlin, with the expansion of the seas, the zonal, diversified continental climates tending toward aridity and refrigeration yield to more uniform, mild atmospheric conditions. A widening of the life zones favorable to limestone deposition follows. Thus in the Devonian, corals thrived in the now ungenial climate of Hudson Bay. With world-wide climatic moderation, a new condition of equilibrium is established between the carbon dioxide of the sea and air. Warm water absorbs less carbon dioxide than cold. The sea begins to contribute its excess of carbon dioxide to the air, in consequence of which the calcium

of the sea becomes still more insoluble. The atmospheric conditions and the land relief favor the floral blanketing of the earth, thus stimulating chemical denudation and creating an effective screen for the retention of clastic materials on the land.

As the waters again withdraw from the lands into the hollows of the sea in response to secular earth movements, they leave composite sediments behind them whose ratio of calcium to magnesium is higher than that of the average igneous rock. With topographic rejuvenation, the muds are again carried toward the margin and to the deep sea, or possibly at times directly to the deep sea as suggested by submerged stream channels, the continuation of existing streams which in some cases extend to the margin of the deep sea. Various parts of the earth are subjected to regional metamorphism and secular uplift, particularly the continental margins, causing selective removal of calcium and the concentration of magnesium in the residuals. The marginal sediments, dominantly clastics, by virtue of position, relief, and a combination of other factors, are in a most favorable position to be removed from the land and swept into the deep sea, where they would be permanently withdrawn from the land. The deposition of clastics is again at a maximum, that of limestones at a minimum. As the pendulum swings from one extreme to another, it marks a curve of progressive change in the composition of the lands and in the ratio of calcium to magnesium in the salts contributed to the sea, consummated by an accumulation of limestones on the continents of progressively higher calcium content, both a reflex and a cause of changes in the land composition, and by the withdrawal of the complementary muds toward the margins and the deep sea, slow during periods of oceanic expansion, but tremendously accelerated during periods of oceanic retreat, selective concentration of magnesium in the deep zones of high temperature and pressure, in the clastics, and in the sea—a never-ending cycle of selective causes and cumulative effects, recalling the words of Faust:

> Wie alles sich zum Ganzen webt,
> Eins in dem anderen wirkt und lebt.

SUMMARY

The problem under discussion is, Why does the dolomite content of the geologic column decrease with time? Is it due to a secondary alteration of limestone after emergence from the sea, roughly proportional to time, or is it due to a gradual decline in the primary development of dolomite in the sea? If the latter, what factors controlling the deposition of dolomite have changed during geologic time, temperature, pressure, life processes, or the chemical composition of the sea?

The conclusions reached are: dolomite develops predominantly in the sea, therefore the decrease in the dolomite content of the sediments in going up the geologic column is mainly due to a decrease in the proportion of dolomite developed in the sea with time.

The factors of deposition whose progressive change has probably controlled the decline of dolomite development in the sea are life processes and the chemical composition of the sea. There is no definite evidence for a change in the nature of the life processes in their relation to dolomite deposition. There is evidence for a change in the chemical composition of the sea; namely, the fact that the present ratio of calcium to magnesium of the streams is probably more than twice that of streams draining crystalline terranes, comparable in composition to the primitive lands. Accepting uniformitarianism, it follows that the present streams have a much higher ratio of calcium to magnesium than the primitive streams. It has been indicated that solutions high in magnesium and low in calcium are more favorable to the development of dolomite than those which are low in magnesium and high in calcium. It is therefore highly probable that the chemistry of the primitive sea was more favorable to the deposition of dolomite than the present ocean.

The increase in the proportion of calcium to magnesium in the streams is believed to be due to selective processes whose effects have been cumulative with time. Rock alterations tend to result in a higher percentage loss of calcium than of magnesium, the materials lost being largely transported in solution to the sea.

A higher percentage of magnesium is retained in the residuals of rock decay than calcium, but erosive processes are constantly removing the residuals toward the margins of the lands, and during periods of continental expansion a considerable proportion is swept into the deep sea and permanently lost from the lands. In consequence of a combination of organic and inorganic agencies, the maximum deposition of limestones and dolomites is on the submerged lands during periods of oceanic expansion. The percentage of calcium precipitated is higher than that of magnesium, but the proportions of calcium to magnesium which are precipitated bear some direct relation to their ratio in the rivers which bring them to the sea. With the progressive elimination of clastics and magnesium from the lands with geologic time, and in their place the gradual accumulation of calcium in the form of limestone, the proportion of calcium to magnesium contributed by rivers to sea has increased with time.

The writer is indebted to C. K. Leith for suggestions and criticisms.

DIFFERENTIATION OF KEWEENAWAN DIABASES IN THE VICINITY OF LAKE NIPIGON

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In recent numbers of *Economic Geology* two papers have been published describing the differentiation products of the quartz-diabases of the Nipissing District, Ontario.[1] Since these diabases have generally been regarded as of Keweenawan age, certain differentiation products of the Keweenawan diabases in the vicinity of Lake Nipigon are also of interest.

On the north shore of Lake Superior and extending northward beyond Lake Nipigon there are masses of diabase and gabbro which intrude the older crystalline rocks in the form of batholiths, dikes, and bosses and the sediments in the form of the "Logan sills." Although there are differences of opinion regarding the geological age of these rocks, the writer concurs with those who regard, as closely related in origin, the great amygdaloidal basalt flows of Keweenaw Point, the Duluth gabbro, the "Logan sills," the Sudbury Nickel eruptive, and the Cobalt diabases, as well as many other masses of diabase in intervening areas. The great igneous activity of this region seems to have been the result of extensive crustal adjustment centered around Lake Superior and diminishing in intensity as a greater distance from the center was reached. It is probable that on the northern side of the Lake Superior basin the intrusive masses were being injected into sediments which had already been formed while the alternate deposits of sediments and lava flows were being deposited on the south side and that a close relationship exists between all portions ot this great series of sediments and extrusive and intrusive igneous rocks.

While a general description of the petrography of these rocks is given here, the object of this paper is to call attention to certain

[1] W. H. Collins, *Econ. Geology*, V, No. 6, p. 538; R. E. Hore, *ibid.*, VI, No. 1, p. 51.

evidences of differentiation which have already been mentioned by Dr. A. P. Coleman and the writer and to add additional notes to the descriptions of this phenomenon.

PETROGRAPHY OF THE DIABASES

The Keweenawan rocks around Lake Superior have been described petrographically in detail, by Irving, Bayley, Van Hise, and many others. In the vicinity of Lake Nipigon the rocks are in many respects similar to those around Lake Superior and they have been described with less detail by Coleman, Wilson, and other geologists. The greater portion of the shores and the islands of this lake consist of basic rock, either diabase or gabbro. Thin sections almost invariably show the ophitic texture more or less well developed, and, although in many places the diabase grades toward gabbro, the greater portion of the rock is diabase. In the sills, diabase always seems to be found, and the same statement may be made of the smaller bodies of the rock, while some of the larger batholithic masses, which have suffered some differentiation, more strongly resemble gabbro.

Structurally the rocks form bosses, large and small, batholiths, or very large irregular masses, dikes, and sills. The dikes are often large, as some were seen in the Onaman Iron Range area 150 ft. in width, and these seem to represent offshoots from the main diabase mass in the vicinity of the lake. The sills, known as the "Logan sills," form beds from two to several hundred feet in thickness. These masses lie between beds of sandstone, shale, or dolomitic limestone, or between these sediments and the underlying Archean rocks, and in all cases studied they present evidence of their intrusive character. Columnar structure is a characteristic of nearly all of the larger masses, especially of the larger sills.

In macroscopical characters these basic rocks generally present a monotonous appearance. They vary in grain from coarse to medium fine and in color from brownish to nearly black. Some of them weather rapidly to granular incoherent masses, and, in the early stages of this weathering, they exhibit in many places cleavage surfaces with a bronze tint. In many cases the ophitic texture is readily recognized in the hand specimen, but in the masses

which tend to become coarse grained and to separate into little aggregations of feldspar and magnetite this texture is lost to a large extent and the rock becomes more like a coarse gabbro. In one place on the shore of Lake Nipigon some sand was collected which showed poikilitic texture where feldspars were inclosed in augite.

In microscopical observations these rocks usually show labradorite, augite, or diopside, and ilmenite or magnetite. Olivine is widespread but is not always present and in specimens without olivine quartz has been found, but it is lacking in many specimens. Biotite appears in small quantities and titanite was found in one section. Since the latter mineral occurs near a dike of acid rock and is not commonly developed in diabases or gabbro, it is believed to be due to the influence of this dike, as some of these acid dikes carry titanite.

Although these rocks are on the whole comparatively fresh, certain alteration products occur. The olivine frequently shows serpentine and iron oxide as alteration products, and the augite and diopside, although usually quite fresh, often contain secondary amphiboles and actinolite. In a specimen from "Haystack Mountain," north of Lake Nipigon, a crystal of magnetite occurs partially surrounded by a mass of actinolite needles which, on revolving the stage of the microscope, show rotary extinction (Fig. 1). These needles seem to be the product of alteration of an augite crystal whose growth began around the magnetite and they resemble similar fibrous growths which W. S. Bayley describes as occurring around magnetite in the basic rocks of the Lake Superior region, although he does not ascribe a secondary origin to them.[1] In a specimen from the shore of Lake Nipigon, opposite "Two Mountain" Island, the diopside and magnetite are intergrown to some extent and the latter sometimes occurs as a fringe along the border of crystals of the former. Although much of the magnetite associated with the

FIG. 1.—Magnetite partially surrounded by augite which has altered to actinolite needles (greatly enlarged).

[1] *Journal of Geology*, I, 702–10.

diopside is primary, some crystals of the diopside which are partially altered to secondary amphiboles contain also undoubted evidence of alteration to magnetite and hematite. While these are unusual alteration products for diopside, analyses of this mineral from gabbro sometimes show as much as 15 per cent of

FIG. 2.—Photomicrograph of diabase showing ophitic texture (crossed nicols; ×40).

iron oxide. The pyroxene is readily recognized as diopside by its characteristic color and extinction angles.

In texture the ophitic character is usually well developed, as the labradorite generally occurs as lath-shaped, nearly euhedral crystals, which penetrate the augite and diopside (Fig. 2) and in some cases are surrounded by them, giving also a poikilitic texture. The rock might therefore be called, to apply the term suggested

by A. N. Winchell for such textures, a poikilophitic rock.[1] In sections of diabase from "Haystack Mountain" the augite is frequently twinned with two members, and instead of the usual stout crystal it occurs in long, narrow forms, somewhat lath shaped, and in this respect resembling the feldspars.

DIFFERENTIATION PRODUCTS; PEGMATITE DIKES

The differentiation products of the Keweenawan rocks of the Lake Superior region have been frequently mentioned. Clements states that the gabbro in Minnesota shows undoubted evidence of differentiation in the large masses of anorthosite and the patches of magnetite and titaniferous iron ore.[2] W. S. Bayley describes peridotites and pyroxenites as very basic phases of the gabbro in his description of the Lake Superior region.[3]

From Lake Nipigon A. P. Coleman describes picrite and other very basic phases of the diabase and also certain acid dikes which are described as post-Keweenawan but closely related to the Keweenawan basic rocks and perhaps differentiation products of them.[4] These rocks are described as having a pegmatitic or micropegmatitic texture and as having the composition of granite or granodiorite.

In "Haystack Mountain" north of Lake Nipigon the writer found similar dikes and from their relationships suggested that they represented an acid phase of the diabase magma.[5] The later observation of similar dikes in the Duluth gabbro near Duluth, Minnesota, confirmed the belief that these rocks are differentiation products of the diabases and gabbros.

The rock at "Haystack Mountain" is a coarse diabase, rather gabbro-like, and shows small, dark patches of titaniferous magnetite and in places lighter blotches consisting largely of feldspar. The magnetite is sufficiently abundant in part of the hill to influence the compass so that prospectors were led to record mining claims

[1] "Use of 'Ophitic' and Related Terms in Petrography," *Bull. Geol. Soc. Am.*, XX (1910), 661–67.

[2] *U.S. Geol. Survey, Monograph XLV*, 397–424.

[3] *Jour. of Geology*, II (1894), 814–25.

[4] *Bureau of Mines of Ontario*, XVII (1908), 163–64.

[5] *Ibid.*, XVIII (1907), 162.

upon it. Besides these small segregations of feldspar there are irregular dike-like masses of similar, light-colored rock and a few fairly distinct dikes, all of small size and varying from one-half inch to a foot in width. These dikes are rather fine grained and in thin section show the following characters. The texture is usually micropegmatitic and one section is composed of about 60 per cent feldspar, 30 per cent quartz, 10 per cent hornblende, and a little magnetite and hematite. The feldspar is chiefly orthoclase with a little albite and the rock is a granite. Another section contains very little hornblende and a little epidote, the rock being composed almost entirely of feldspar in the proportions of 65 parts orthoclase to 35 parts plagioclase. This rock is a syenite grading toward a monzonite. Still another section is from a dike which might be regarded as a monzonite. It contains a little enstatite, epidote, and titanite, while the greater portion of the rock is feldspar and in the proportions of about 66 per cent albite and oligoclase and 34 per cent orthoclase. A fourth section is from an augite-syenite dike in which the orthoclase makes up 75 per cent and the sodic variety 25 per cent of the feldspar. There are a good many small augite crystals and the micropegmatitic texture is well developed. A section of a dike from near "Two Mountain" Island is also an augite-syenite.

The most interesting dikes in the region are those occurring on Flat Rock Portage near the south end of Lake Nipigon. At this point a large mass of rock, described by Coleman as a sill of epi-basalt or fine-grained diabase-porphyrite, is cut by a pegmatite dike varying in width from three inches to one foot. Where the diabase has suffered columnar jointing the fissures have filled with acid rock similar to the flesh-colored or pink dikes described above (Fig. 4). The surface of this sill is flat and fine grained, and when the glacier passed over it interesting chatter-marks were left. The pegmatite dike is medium coarse grained, flesh colored, and appears to be composed very largely of feldspar. Under the microscope the pegmatitic intergrowth of various minerals and the graphic intergrowth of quartz and feldspar are well developed. The rock consists of quartz in proportion of 10 per cent, epidote 10 per cent, and sodium-calcium feldspar 80 per cent. The

feldspars show a wonderful development of the zonal structure (Fig. 3). In the rapid growth of the crystals the zones of calcium- and sodium-rich material have developed mostly at their ends, and they have thus been drawn out to excessive linear proportions. The indices of refraction indicate that the most calcic feldspars form the central zone and the more sodic follow outward. The usual order of rate of weathering of the sodic and calcic feld-

FIG. 3.—Photomicrograph of a section from a pegmatite dike at Flat Rock Portage showing unusual development of zonal structure in sodium-calcium feldspar (crossed nicols; ×40).

spars does not hold in many of these crystals, as the second zone even with lower index of refraction often shows much more extensive alteration than the central zone. The alteration products are epidote and a mineral or mixture of minerals which has yellowish polarization colors and is believed to be epidote, kaolin, and zeolites. A peculiar influence of the pegmatitic intergrowth of the minerals is the crystallization of epidote in some of the zones

replacing the feldspar. This arrangement was seen where the path of an epidote crystal was cut across by that of the growing, zonally built feldspar. In a couple of cases a group of epidote crystals is crossed by feldspar, but the simultaneous extinction of all parts of the epidotes shows them to be parts of the same crystal and in one case particularly a portion of the epidote crystal has passed through the feldspar, forming one of the zones of the crystal. In these cases the epidote is undoubtedly primary, although considerable secondary epidote occurs from alteration of the feldspars.

An interesting example of a crushed feldspar is seen in this section where the crystal has been broken into slivers and the fragments surrounded by quartz. This must have been due to pressure, although the rock as a whole does not show evidence of excessive pressure beyond the undulatory extinction of some of the quartz grains.

In his description of the copper-bearing rocks of Lake Superior, Irving describes some sections from dikes of red rock in the Duluth gabbro which would indicate that they are probably similar to those dikes described above.[1]

These acid dikes appear to be differentiation phases of the Keweenawan diabases and gabbros because they occur, with one exception, in these rocks only, and, so far as observed, only in the larger masses and not in the thin sills which are too small to produce them by differentiation. This one exception is a dike 30 inches wide cutting quartzite and the overlying diabase near Ombabika Narrows.[2] This dike might be due to the rising of the liquid from some large diabase mass below through a fissure extending into the overlying rocks. There are no other bodies of acid rock in the region later in age than the Keweenawan diabases, and the pegmatitic and micropegmatitic textures suggest end phases of a magma. These dikes probably fill crevices in the diabase formed in the solidified exterior of a large mass, due to adjustment of pressures during processes of cooling, and the acid material rose from the still hot and more acid lower portions of the mass. The fact that these dikes are so much more basic on the whole than

[1] *U.S. Geol Survey, Monograph V*, 119–20.

[2] Coleman, *Bureau of Mines of Ontario*, XVII, 164.

the aplites of the Cobalt area may be due to the fact that the magma from which they separated was on the whole more basic. The ophitic texture of the diabases indicates a magma early saturated with calcium. The alkalies, being in small quantity, were mostly left over until the end of the crystallization period and then united with the remaining aluminium and silica to form potassium or sodium feldspars, while the small excess of silica occurring in a few places

FIG. 4.—Acid dikes filling columnar joint fractures in diabase.

went to form quartz. It is thus assumed that the magma became saturated with the more basic materials first, and the remaining acid materials, still liquid, were in some cases crowded toward the lower and central portion of the mass to escape into the fissures when opened, and form dikes.

In the case of the pegmatite dike in which the feldspar is largely calcic and occurs with the silica, it is probable that the excess of magnesium and iron caused the rocks to become saturated with

these elements, and the augite and olivine, separating out earlier, caused some of the calcium and aluminium to be left over to enter the dike.

It is interesting to note that in the Sudbury and Cobalt areas, where the Keweenawan rocks have suffered very great differentiation compared with that in the Lake Nipigon region, there are extensive ore bodies connected with them, while there is nothing but a little iron ore in the Nipigon region, and this occurs at the contact with sediments and may be leached from them.

While differentiation of magmas and thus the separation of the metals, as well as other elements, from the magmas, may be only one factor in the development of mineral veins as well as magmatic segregations, it seems probable that all data collected on this subject will show this is one of the important factors. Other things being equal, if the igneous rocks are the source of the metals, those magmas which show the greatest differentiation should be the most favorable for the production of ores, whether they supply metal-bearing solutions directly to the veins—a process quite conceivable in some cases—or whether they cause segregation of the metals so that they can readily be dissolved by meteoric waters in sufficient quantities to form ore deposits in veins.

GENERA OF MISSISSIPPIAN LOOP-BEARING BRACHIOPODA

STUART WELLER

Introduction

The correct specific determination of the loop-bearing brachiopod shells of the Mississippian faunas has always been attended with difficulty. This condition led the writer to undertake a critical study of a large amount of material, in order to determine, if possible, the true criteria for the determination of species. In this study the internal characters of the shell, as well as the external configuration, have been taken into consideration.

In the earlier literature all the shells of this type were included in the genus *Terebratula*, but since the appearance of Hall and Clarke's great work on the *Genera of Paleozoic Brachiopoda*,[1] it has been the usual custom to refer all of them to the genus *Dielasma*, although Girty has described one form as a member of the genus *Harttina*.[2] As a result of the present investigation, however, it has been found that forms which have been commonly included in a single genus, and in some instances, even, forms which have been referred to a single species, in reality represent several perfectly distinct generic types. The method used in the investigation is that which has been formerly used in the study of the Rhynchonelloid shells. Specimens have been ground from the posterior extremity and at short intervals the ground surface has been polished and a careful drawing made of the cross-section of the shell parts shown. From such a series of cross-sections of any shell it is easy to recognize the character and position of the internal lamellae, such as the median septum, the hinge-plate, the socket-plates, the bases of the crura, etc. In the course of the study it has been shown that the characters which can be considered as of

[1] *Paleontology of New York*, Vol. VIII, Parts 1 and 2.

[2] "*Harttina indianensis* Girty," *Proc. Nat. Mus.*, Vol. XXXIV, p. 293.

generic value in these shells are to be found in the rostral portion of the brachial valve. Six and possibly seven good generic groups have been recognized, and will be defined here.

DIELASMA King

Description.—Shell terebratuliform. Pedicle valve with or without a median sinus, the beak strongly incurved, the foramen large and encroaching upon the umbonal portion of the valve; internally with well-developed dental lamellae. Brachial valve usually without mesial fold; internally the crural plates are separate from the dental socket-plates, they diverge from the apex of the valve with an elongate attachment to the inner surface of the valve, the free portion of the brachidium is short, with diverging

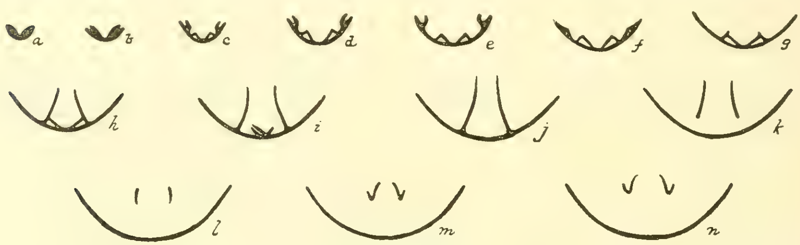

FIG. 1.—A series of fourteen cross-sections ($\times 2\frac{1}{2}$) of the rostral portion of the brachial valve of *Dielasma formosa* Hall.

descending lamellae; between the crural plates for the full length of their attachment to the inner surface of the valve, is a concave, transverse plate for muscular attachment, which joins the inner surface of the crural plates a little above their base; this plate rests against the inner surface of the valve along the median line for a portion or the whole of its length, or it may be free throughout; when attached along the median line a pair of slender cavities, triangular in cross-section, converge from the general cavity of the shell toward the beak, but when the transverse plate is not attached along its median line there is a single, broad and low cavity beneath the plate, extending toward the apex; anteriorly this plate extends to a greater or less distance beyond the attachment of the crural plates and is pointed, rounded, or emarginate in front; its surface is marked by concentric wrinkles parallel with

its anterior margin which are usually discontinuous along the median line.

Remarks.—The genus *Dielasma* was established by King with *Terebratula elongatus* Schl. as genotype, and although he defined the genus primarily upon the presence of prominent dental lamellae in the pedicle valve, and on the form of the loop, his illustrations of the internal casts of the species under the name *Epithyris elongata*[1] show that the crural plates are separate from the socket walls, one of the most essential features of *Dielasma* as here defined. Davidson[2] gives illustrations of the same species which exhibit all the essential generic characters of *Dielasma* most perfectly. The interpretation of the genus by Hall and Clarke[3] is identical with that here given, but those authors included certain species in the genus without sufficient investigation of their internal characters, which are fundamentally different; it has in fact been the usual custom among American workers, since the publication of Hall and Clarke's work, to refer all Mississippian terebratuloid shells to the genus *Dielasma*.

In specimens preserved in the condition of internal casts the generic characters of *Dielasma* are always very obvious, the position of the crural lamellae, separate from the socket-plates, being indicated by a pair of slits diverging from the beak of the brachial valve; when the transverse muscle-bearing plate is attached along its mesial line a second pair of diverging slits are present between those formed by the crural lamellae, and the finger-like casts of the slender cavities beneath the transverse plate are clearly shown, whether they are actually present or broken off. In specimens having the shell preserved the shell substance is frequently translucent enough to show the position of the internal lamellae as dark lines, in which case the genus can be recognized at once, and when the shell is opaque it is usually easy to determine the generic characters by the judicious use of a needle, without injuring the specimen as to its external form and characters upon which the various species are differentiated.

[1] *Monog. Perm. Foss. England*, Pl. 6, Figs. 37, 41 (1850).

[2] *Brit. Foss Brach.*, II, Permian, Pl. 1, Figs. 18, 20.

[3] *Pal. N.Y.*, VIII, Pt. 2, pp. 293–94.

Genotype.—*D. elongata* (Schl.). Other species, *D. formosa* (Hall), *D. shumardianum* (Miller), *D. fernglenensis* Weller, *D. burlingtonensis* White.

GIRTYELLA n. gen.

Description.—Shell terebratuliform. The pedicle valve sinuate, with a large, subcircular or subovate, oblique foramen which encroaches upon the umbo; the brachial valve frequently sinuate and often with a slight median fold in the bottom of the sinus. Internally the dental lamellae are well developed in the pedicle valve. In the brachial valve the socket-plates are joined by a concave hinge-plate which is imperforate at the apex and is supported by a median septum; the inner sides of the dental sockets

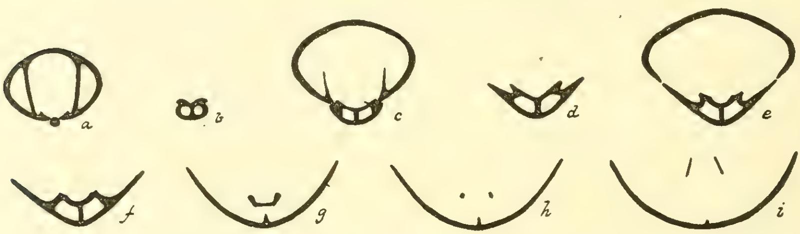

FIG. 2.—A series of nine cross-sections ($\times 2\frac{1}{2}$) of the rostral portion of the shell of *Girtyella indianensis* (Girty), three of which show both the pedicle and brachial valves, the others showing only the structure of the brachial valve.

retreat from the margins of the valve anteriorly beyond the point of articulation, and become the bases of the crura which are still joined by the concave hinge-plate and are also supported by lamellae resting against the inner surface of the lateral slopes of the valve. The brachidium short, its free portion apparently being like that of *Dielasma* and not reaching to the middle of the shell.

Remarks.—Members of this genus have commonly been included in the genus *Dielasma*, but they differ fundamentally from that genus in the presence of a median septum supporting the hinge-plate of the brachial valve, and in the origin of the bases of the crura from the socket-plates. In his description of the species which is selected as the genotype, Girty referred the form to the genus *Harttina* on account of the presence of a median septum in

the brachial valve, but the brachidium of *Harttina* is elongate, like that of *Cryptonella*, reaching nearly to the front of the shell, while that of *Girtyella* is short, like the brachidium of *Dielasma*.

Genotype.—*G. indianensis* (Girty). Other species, *G. turgida* (Hall), *G. brevilobata* (Swall.).

DIELASMOIDES n. gen.

Description.—Shell terebratuliform. Pedicle valve bisinuate toward the front in the genotype, the two depressions separated by a low, broadly rounded mesial elevation; the foramen large, oblique, encroaching wholly upon the umbonal region. Brachial valve with a slight mesial flattening or depression anteriorly in the genotype. Internally the dental lamellae are well developed in the pedicle valve; in the brachial valve the socket-plates are supported at their inner margins by a pair of lamellae which pass obliquely toward the floor of the valve to which they are joined

FIG. 3.—A series of seven cross-sections ($\times 2\frac{1}{2}$) of the rostral portion of the shell of *Dielasmoides bisinuata* n. sp., in the last three of which only the brachial valve is shown.

near the median line; between these lamellae, the outer walls of the valve and the socket-plates, are a pair of cavities narrowly triangular in cross-section which expand anteriorly and open out into the general cavity of the valve; the crura originate from the anterior extensions of the inner walls of the socket-plates. Form of the brachidium not known.

Remarks.—The characters of the rostral cavity of the brachial valve in this genus differ from those of *Dielasma* in the absence of any special crural lamellae distinct from the socket-plates. The two rostral cavities, narrowly triangular in cross-section, have a superficial resemblance in the two genera, but the narrow base of the triangle in this genus is formed by the socket-plate, while in *Dielasma* it is formed by the basal portion of the crural lamellae, and the special muscle-bearing plate between the bases of the crural lamellae of *Dielasma* is absent in this genus. This form is

perhaps to be compared with *Girtyella* as the genus most closely allied to it. If the concave hinge-plate of *Girtyella*, which is supported by a median septum, be depressed along its median line to such an extent that the concave plate itself rests directly upon the floor of the valve, the median septum being eliminated, then we would have essentially the characters shown in this genus. The bisinuate folding of the anterior portion of the pedicle valve may be a generic character, but this cannot be determined from the single species so far recognized.

Genotype.—*D. bisinuata* n. sp., St. Louis (?) oolite, Lewis County, Mo.

CRANAENA Hall and Clarke

Description.—Shell terebratuliform. Pedicle valve with or without a median sinus and with well-developed dental lamellae

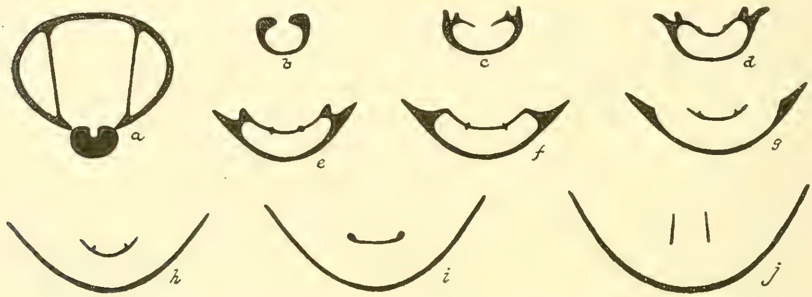

FIG. 4.—A series of ten cross-sections ($\times 2\frac{1}{2}$) of the rostral portion of the shell of *Cranaena iowensis* (Calvin), from all but the first of which the pedicle valve has been omitted.

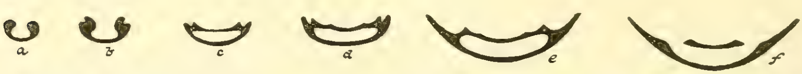

FIG. 5.—A series of six cross-sections of the rostral portion of the brachial valve of *Cranaena* sp. undesc., residual chest, Springfield, Mo.

of moderate length internally, the foramen large, oblique, and encroaching upon the umbonal portion of the valve, the beak incurved. Brachial valve without median fold, even in those species with a well-defined sinus in the opposite valve, but sometimes with a slight mesial depression near the front margin; internally the well-developed socket-plates are connected transversely

by a concave hinge-plate which is perforated at the apex of the valve posteriorly; upon the inner or concave surface of the hinge-plate a pair of ridges originate at or near the anterior margin of the perforation and continue anteriorly across the plate, from the front of which they are produced into the crura. These crural ridges divide the hinge-plate into three equal divisions, or into two equal lateral divisions and a broader central one, and in some species the crural ridges are accompanied by similar ridgelike thickenings upon the opposite side of the hinge-plate. The brachidium short and *Dielasma*-like, not reaching to the middle of the valve.

Remarks.—This genus differs fundamentally from *Dielasma* in the origin of the crura from the thickened crural ridges of the hinge-plate, rather than from crural lamellae resting upon the inner surface of the valve, and in the absence of a special plate in the brachial valve for muscular attachment, the muscles being attached directly to the inner surface of the valve. From *Girtyella* the genus differs in the perforation of the hinge-plate, in the absence of a median septum in the brachial valve, and in the origin of the crura from crural ridges of the hinge-plate rather than from the anterior extension of the inner extremities of the socket-plates.

Genotype.—*C. romingeri* (Hall). Other species, *C. iowensis* (Calvin), *C.* n. sp., residual chert, Springfield, Mo.

HAMBURGIA n. gen.

Description.—Shell terebratuliform. Pedicle valve not sinuate in the genotype and only known species, the foramen large, oblique, encroaching upon the umbonal region; brachial valve without fold or sinus. Internally the pedicle valve is supplied with well-developed dental lamellae; the brachial valve with well-developed socket-plates which retreat from the lateral margins of the valve anteriorly beyond the articulation of the valves; they are connected transversely by a deeply concave hinge-plate which is separated from the inner surface of the valve by an exceedingly low and broad cavity; upon the inner or concave side of the hinge-plate a pair of ridges originate toward the apex and diverge

slightly while becoming stronger anteriorly, finally passing into the bases of the crura; shortly in front of the point of origin of the crural ridges on the hinge-plate the socket-plates are rapidly reduced in height and soon become obsolete, beyond which point the hinge-plate is not connected with the inner surface of the valve, but becomes a concave plate joining the bases of the crura and terminating anteriorly in a short distance. The complete form of the brachidium is not known, but it is probably short, not reaching the mid-length of the valve.

Remarks.—This genus is perhaps most closely allied to *Cranaena*, from which it differs in the extreme concavity of the hinge-plate, the cavity between it and the inner surface of the valve being reduced in height, and in the absence of the perforation of the

FIG. 6.—A series of nine cross-sections ($\times 2\frac{1}{2}$) of the rostral portion of the brachial valve of *Hamburgia typa*, n. sp.

hinge-plate at the apex, which is, perhaps, the most diagnostic character. The genus is totally distinct from *Dielasma*, in which the crural plates originate as ridges upon the inner surface of the valve instead of upon the concave surface of the hinge-plate. The concave, transverse plate between the bases of the crura is somewhat similar in the two genera except that it is not connected along its median line to the inner surface of the valve in *Hamburgia*, but in *Dielasma* the inner surface of this plate furnishes attachment for the adductor muscles, which is apparently not true in *Hamburgia*.

Genotype.—*H. typa*, n. sp., Hamburg oolitic limestone of Kinderhood age, Hamburg, Ill.

DIELASMELLA n. gen.

Description.—Shell terebratuliform, compressed. Pedicle valve with well-developed dental lamellae of moderate length. Brachial valve without median septum or true hinge-plate, the socket-

plates well developed, retreating from the lateral margins of the valve anteriorly and becoming differentiated into two portions, a basal portion which joins the inner surface of the valve and is directed obliquely inward, and a distal portion which is abruptly bent in a subgeniculate angle so as to be directed obliquely outward; the portion included in the angular bend of the two plates is produced anteriorly into the bases of the crura, and just before the crura become free a narrow transverse band joins their bases. The characters of the brachidium not completely determined, but it is believed to be of the short, *Dielasma*-like type. Shell structure finely punctate.

Remarks.—In the arrangement of the internal features of the apical portion of the brachial valve this genus is perhaps more closely allied to *Cranaena* than to any other of the generic types here recognized. It differs from *Cranaena* chiefly in the reduction

FIG. 7.—A series of six cross-sections ($\times 2\frac{1}{2}$) of the rostral portion of the brachial valve of *D. compressa* (Weller).

of the hinge-plate to a narrow, transverse band joining the crural bases, while in *Cranaena* it is elongate, with a comparatively small apical perforation, and with the crura originating as a pair of ribs diverging anteriorly from near the apex. The difference in shape, viz., the compressed shell and the erect beak of the pedicle valve, are other features which easily separate the members of this genus from all species of *Cranaena* which have been recognized.

Genotype.—*D. compressa* (Weller). Glen Park limestone.

ROWLEYELLA n. gen.

Description.—Shell terebratuliform, with the valves subequally convex. The beak of the pedicle valve perforated by a subcircular foramen which encroaches wholly upon the umbonal region, the delthyrium broadly triangular and wholly closed. Internally each valve is supplied with a strong median septum which, in the pedicle valve, reaches nearly to the center of the valve, that of the brachial valve being somewhat shorter.

Remarks.—The relationships of this genus cannot be certainly determined from the material available for study. The general contour of the shell at once suggests its affinity with the terebratuloid, loop-bearing shells, as also does the character of the foramen of the pedicle valve, and so far as it can be observed the delthyrium and its covering. The shell structure has not been certainly determined. Upon one example a punctate structure is slightly suggested, but that characteristic structure of the terebratuloids cannot be said to be demonstrated. The characteristic of these shells which is most foreign to the terebratuloids is the strongly developed mesial septum of the pedicle valve, which evidently supports a well-developed spondylium, and the presence of this character in association with a strong median septum in the brachial valve suggests the family Pentameridae, but it has not been determined that a cruralium accompanies this median septum of the brachial valve. This feature of a median septum in the pedicle valve has not been recognized heretofore among the loop-bearing terebratuloids, although there is perhaps no reason why it should not exist, but a median septum in the brachial valve occurs in at least one genus of these shells.

In any event the characters exhibited by these shells exclude them from any described genus among either the terebratuloids or the pentameroids. The presence of a pedicle median septum is sufficient to differentiate the genus from any other of terebratuloids, if indeed it be one of these shells, and the characters of the foramen and delthyrium differentiate it from any pentameroid. The shell perhaps agrees most closely in the sum of all the characters present with the spire-bearing *Camarophorella,* but there is no evidence, in the specimens observed, of the presence of a brachial platform associated with the median septum of that valve, as is true in *Camarophorella.*

Genotype.—R. fabulites (Rowley), Burlington white chert, Louisiana, Mo.

PHYSIOGRAPHIC STUDIES IN THE SAN JUAN DISTRICT OF COLORADO[1]

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The University of Chicago

The studies during the past field season were carried on near the southern and southwestern margin of the San Juan Mountains and over the adjoining plateau district. Investigations were planned for the purpose of working out the complete physiographic history of the district. The courses of the Pleistocene glaciers were indicated on the maps and the deposits left by those glaciers differentiated. In connection with these studies it was possible to differentiate the moraines of two distinct glacial epochs in each of the large canyons examined. Beyond the terminal moraines of each epoch and extending for many miles down stream, terrace remnants of valley trains were recognized. It was evident from the position of the younger glacial moraines and younger outwash valley trains that there had been a notable amount of valley deepening in hard rocks during the interglacial epoch. This suggests that the mountain area had been elevated by at least several hundred feet relative to sea-level during the Pleistocene period. The glacial features on the south slope of the range did not differ from glacial features which have been fully described by various writers who have become familiar with glacial phenomena in the high mountains of the West.

In examining the areas which rose above the upper limit of ice action on the south slopes of the mountains, certain gravel-strewn surfaces were found. The gravels were beautifully polished and of very resistant material. They were composed chiefly of quartzite, quartz, red jasper, flint, cherts, and greenstones. Much of the material was less than half an inch in diameter, but some of the pebbles ranged between one and two inches in their longer

[1] Published with the permission of the Director of the U.S. Geological Survey.

axes. The surfaces on which these gravels were found were along the crests between the great mountain canyons and on the tops of mesa-like hills near the base of the range. If the gravel-strewn surfaces were extended they would unite and form a plain of gently rolling topography. That plain would slope away from the core of the range, show a distinct warping at the base of the range, and pass off over the upland surfaces of neighboring plateaus. The nature and distribution of the gravels suggested that they were remnants of stream deposits in channels which formerly crossed the present inter-canyon ridges. They appeared to be the deposits of streams which flowed over low gradients and suggested further, by their distribution and the distribution and relations of the surfaces on which they were found, a deformed peneplain. In following this ancient erosion surface southward and southwestward over the plateau district it seemed that certain of the outlying mesa surfaces would correspond in age to this peneplain surface, and it was anticipated that on such outlying surfaces a mantle or scattering of still finer gravels might be found. But these mesa surfaces were found to carry a heavy mantle of bowlder-gravels, in which the larger masses ranged up to three and four feet in diameter. In these bowlder-gravel deposits certain special bowlders could be recognized which came from outcrops in the mountain areas, and it appeared that they must have been washed out and deposited as a portion of a great alluvial fan about the margin of the mountains. These bowlder-strewn surfaces were followed southward nearly fifty miles from the base of the range, and at that distance the larger bowlders seen ranged to at least three feet in diameter. The interpretation of this bowlder-gravel mantle and its relation to the erosion surfaces upon which it rests and the erosion surfaces in the mountains which seem to correspond in age to those underneath the bowlder-gravels is that at the close of the cycle of erosion during which the peneplain as described was developed, there was a general uplift in the district, which was emphasized in the San Juan dome. The headwaters of the streams in the uplifted dome were so rejuvenated that they carried together with sands and gravels many large bowlders to the base of the range and spread that material out as

alluvial fans over the neighboring plateaus. The streams which crossed the plateaus were first rejuvenated in their lower courses, and as rejuvenation worked upstream across the broad plateaus the growth of the great alluvial fans ceased and their dissection began. The high-level bowlder-gravels are, therefore, a deposit which marks the beginning of a new period of erosion in the mountains and a temporary period of alluviation about the base of the mountains. The bowlder-gravels are, therefore, not of exactly the same age, but a little younger than the small peneplain gravels of the mountain area.

Below the summit elevations in the mountains and in the neighboring plateaus there are other broad bowlder-capped mesa-like forms which appear to represent the base to which the streams worked when the peneplain was first deformed. The bowlder capping on these mesas is at places as much as thirty feet in thickness. The Florida and Fort Lewis mesas just south of the San Juan Mountains are typical of this bowlder-mesa stage in the dissection of the area. Another uplift associated with the more or less continuous growth of the mountains deformed the graded surfaces of the bowlder-mesa stage, again rejuvenated the streams, and opened another cycle of erosion. The surfaces to which the streams then worked are represented by broad, open valleys of late maturity or early old age in the softer rocks, and by canyons in the harder rocks. This cycle of erosion has been for convenience referred to as the Oxford stage, for there is an excellent development of the typical lowlands of this stage near the village of Oxford, a few miles southeast of Durango. It immediately preceded the first epoch of glaciation as recorded by the moraines and outwash deposits found on the south slope of the range. In the mountain-canyons the bowlder-mesa and Oxford stages are both represented by rock benches which in some instances carry stream alluvium.

These studies have opened certain large problems in the relationship of the mountains to the plateaus, and suggested a close correlation in the physiographic histories of the two provinces. Are the high-level bowlder-gravels resting on a true peneplain? Of what age is this peneplain? In the area examined during the

past season it is known to truncate Wasatch beds. Is it not, however, as late as late Miocene? Does it correspond in age to the great peneplains of the Grand Canyon district?[1] Are the high-level bowlder-gravels bordering the Front Range of the Rocky Mountains, the Big Horn Mountains,[2] the Livingston Range[3] of the same age as these about the San Juan Mountains? Do they rest on peneplain surfaces? Is the Blackfoot Peneplain of Montana described by Bailey Willis[4] of the same age as the one observed in this region? Are the Wyoming conglomerates about the base of the Uinta Mountains, placed in the Pliocene by the King Survey,[5] of the same origin and age as the high-level bowlder-gravels south of the San Juans? What is the relationship of certain bowlder deposits found near the summit and near the core of the San Juans, and certain ancient stream gravels which have been found by Stone, near the summit of the Front Range, to the bowlder-gravels about the bases of these ranges? Numerous other correlations in the Rocky Mountain areas and in the Pacific Coast mountains are suggested. Has there been with each period of mountain growth in the Cordilleran region of North America a rejuvenation of the streams which affected the headwaters long before it affected the middle courses of the rivers, and did these rejuvenated headwaters distribute the bowlder-gravels in each case on the neighboring plateaus? How far were such deposits carried and how were the larger bowlders transported? Numerous cases may be cited where bowlders ten to twelve feet in diameter have traveled at least twenty-five miles from their sources over surfaces of very low gradient. If such bowlders can travel twenty-five miles on gently sloping surfaces, is it not possible for them to travel much farther than that over low gradients? How are huge bowlders transported over nearly horizontal surfaces? How far have climatic changes affected the work of streams in the Rocky Mountain region? Are the reported glacial deposits in southeastern

[1] H. H. Robinson, *Am. Jour. Sci.*, 4th Series (1907), XXIV, 109–29.

[2] Salisbury and Blackwelder, *Jour. Geol.*, II (1903), 220–23.

[3] Bailey Willis, *Bull. Geol. Soc. Am.*, XIII (1902), 329–30.

[4] *Op. cit.*, 310.

[5] Hague and Emmons, *Rep. of 40th Parallel Survey* (1877), II, 64–65, 188–89 ff.

Utah,[1] in which there are granitic and gneissic bowlders one to five feet in diameter, the origin of which is at present unknown unless it be the San Juan Mountains, true glacial deposits or stream deposits? Could mountain glaciers from the San Juan Range have reached southwestward one hundred miles from the base of the range? Is there not some other explanation for the coarse bowlder deposits reported in that portion of the plateau district?[2] Has there been a continuous or periodic growth of the San Juan dome during late Tertiary and Quaternary times?[3] How are the great systems of fissures which cut the late Tertiary volcanics related in age to the recent deformative movements? Co-operative work by all who are engaged in field studies in the Rocky Mountains and plateau provinces should prove of great value in promoting the solution of these problems.

[1] D. D. Sterrett, *U.S. Geol. Survey, Mineral Resources* (1908), Pt. II, 825 (1909).

[2] W. M. Davis, *Proc. Am. Acad. Arts and Sci.*, XXXV (1900), 345–73.

[3] Cross and Spencer, *U.S. Geol. Survey 21st Ann. Rep.* (1900), Pt. II, 100.

THE VARIATIONS OF GLACIERS. XVI[1]

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Johns Hopkins University

The following is a summary of the *Fifteenth Annual Report* of the International Committee on Glaciers.[2]

REPORT OF GLACIERS FOR 1909

Swiss Alps.—Of the ninety glaciers measured in 1909, only two have been advancing for three successive years, the Scex-rouge and the lower Grindelwald Glacier; the latter has advanced 59 meters in two years. Nine other glaciers have advanced slightly during the last year but it is not certain that they are in a stage of advance. A general retreat is dominant in the Swiss Alps.[3]

Eastern Alps.—Thirty-nine glaciers were measured, and the retreat is general, although in many cases it is slow. The Langtaler Glacier and the Grosselendkees seem to be stationary, and the Mitterkarferner has made a small advance.[4]

Italian Alps.—The retreat, which has been general for some years, seems to be continuing without change.[5]

French Alps.—Observations on the snow-fall and the variation in the length of glaciers have continued, and maps of some glaciers are being made on a scale of 1 : 10,000. In the Mont Blanc range the retreat is nearly general, though slight; the Glacier des Bossons has advanced a little more than one meter. The ends of the glaciers have in general diminished in thickness with a corresponding diminution in the velocity of flow. In the Tarentaise and Maurienne the retreat is also general, but feeble. In the Dauphiné we find that the snow-fall has been distinctly heavier since 1906 with the result that the glaciers on the northern side of the Pelvoux massif have grown thicker and are beginning to advance; and the

[1] The earlier reports appeared in the *Journal of Geology*, Vols. III–XIX.

[2] *Zeitschrift für Gletscherkunde* (1911), V, 177–202.

[3] Report of Professor Forel and M. Muret.

[4] Report of Professor Brückner. [5] Report of Professor Marinelli.

whole appearance of the reservoirs indicates that the advance in this region will become general. In the southern part of the same massif, although the increase in the snow-fall is also marked, the retreat of the glaciers continues. In the Pyrenees the snow-fall has been heavy since 1906 and the small glaciers show a marked tendency to increase in size.[1]

Swedish Alps.—A number of glaciers have been measured and the changes resulting during a variable number of years up to 1909 indicate a slight increase in general, though a few of the glaciers are apparently stationary and one or two slightly retreating.[2]

Norwegian Alps.—The difference in the behavior of the glaciers of Jotunheim, in the interior of Norway, and those of Folgefon and Jostedalsbrä, near the coast, which was commented on in the last report, continues. The glaciers near the coast are generally advancing, whereas those in the interior are generally retreating.[3]

Russia.—The greater part of the glaciers observed in the Caucasus between 1899 and 1907 have retreated. A few have remained stationary and only two have made an advance. A number of glaciers in the Altai and Muss-tau mountains, in Siberia, have been visited but no careful measurements made.[4]

REPORT ON THE GLACIERS IN THE UNITED STATES FOR 1910[5]

There are a number of small glaciers in Colorado which, on the whole, show a tendency to become smaller, but their variations from year to year are extremely slight.[6]

The Hallett Glacier shows no measurable change since 1909 (Mills).

The Carbon Glacier on the northern side of Mt. Rainier is in marked recession (Matthes).

The United States Geological Survey has been continuing its

[1] Report of M. Rabot.

[2] Report of Professor Hamburg.

[3] Report of M. Oyen.

[4] Report of Colonel Schokalsky.

[5] A synopsis of this report will appear in the *Sixteenth Annual Report* of the International Committee. The report on the glaciers of the United States for the year 1909 was given in this Journal (XIX, 83–89).

[6] All available information regarding these glaciers has been collected by Judge Junius Henderson, "Extinct and Existing Glaciers of Colorado," *University of Colorado Studies* (1910), VIII, 33–76.

explorations and surveys of Alaska, and several glacier regions have been mapped. A number of glaciers north of Juneau are in rapid recession. The glaciers in the neighborhood and north of the headwaters of the Copper River (in the neighborhood of latitude $63\frac{1}{2}°$ N and longitude $145°$ W) seem to be retreating slowly (Brooks).

Fresh moraine, extending for nearly two miles at the end of Nabesna Glacier, shows that it is retreating rather rapidly. The Chisana Glacier, 15 miles to the east, has a very clean end; a comparison of photographs taken in 1899 and 1908 shows surprisingly little change in the aspect of the glacier, though at one place a slight recession has taken place. Frederika Glacier, entering White River valley from the north, when seen by Dr. C. W. Hayes in 1891 ended "in a nearly vertical ice cliff . . . . about 250 feet high. At the foot of the cliff there is a small accumulation of gravel and ice fragments apparently being pushed along by the advancing mass."[1] In 1909 Mr. Stephen R. Capps says "its surface is remarkably smooth and slopes down evenly to a thin edge in front." The Frederika Glacier has evidently changed from an advancing to a retreating glacier in the interval. Exactly opposite Frederika Glacier another glacier, in retreat in 1891, is now advancing.[2]

Such spasmodic cases are probably produced by sudden accession of material due to avalanches or land slides, rather than to simple variations in snow-fall or temperature.

The Ruth Glacier, rising on Mt. McKinley and extending many miles to the east, is slowly diminishing in size (Rusk).

Professor U. S. Grant and Mr. D. F. Higgins have published a general map of Prince William Sound, showing the location of all the glaciers, on a scale of 4 inches to the mile.[3] They have also published descriptions, pictures, and detailed maps of the ends of several of these glaciers.[4] The last observations were made in

[1] "Expedition through the Yukon District," *Nat. Geog. Mag.* (1892), IV, 153.

[2] "Glaciation on the North Side of the Wrangell Mountains, Alaska," *Jour. Geol.* (1910), XVIII, 56.

[3] "Reconnaissance of the Geology and Mineral Resources of Prince William Sound, Alaska," *U.S. Geological Survey, Bulletin No. 443*, Washington, 1910.

[4] "Glaciers of Prince William Sound and the Southern Part of the Kenai Peninsula, Alaska," *Bull. Amer. Geog. Soc.* (1910), XLII, 721–33.

the summer of 1909 and we note that the Shoup Glacier was practically stationary and was fully as large then as it had been for several decades. The Columbia Glacier was found, at its eastern edge, about 500 feet in advance of its position of 1899, and this advance seems to have taken place principally since the summer of 1908. Professor Grant found indications that the glacier was well in advance some fifty years ago and before that date was considerably smaller. The Meares Glacier seems to be a little in advance of its position of 1905, and the general condition of the vegetation in the immediate neighborhood indicated that the glacier in 1909 was probably as far forward as it has been during the last one hundred years or more.

Professor Lawrence Martin conducted another expedition for the National Geographic Society in 1910 to study the Alaskan glaciers. He sends me the following notes:

Fairweather Range.—La Perouse Glacier advanced approximately a quarter mile between September 4, 1909, and June 10, 1910, and was destroying forest on the latter date, as it had previously done in September, 1895.

Yakutat Bay.—Nunatak Glacier advanced 700 to 1,000 feet between July 6, 1909, and June 17, 1910, after retreating steadily at least 2½ miles from 1890 to 1909. Hubbard Glacier did not continue to advance as rapidly as seemed possibly would be the case in 1909, parts of the front advancing 600 feet between 1909 and 1910 while other parts retreated 500 to 1,000 feet. In 1910 Lucia Glacier had probably nearly ceased the great advance which was in progress in July, 1909. Nunatak Glacier is the ninth ice tongue in the Yakutat Bay region to advance since 1899, following a long period of continuous retreat or stagnation. In each case listed below the advance is thought to be the result of great accessions of snow and ice by avalanches during the earthquakes of September, 1899.

Glacier	Date of Advance	Length of Glacier
Galiano*	After 1895 and before 1905	2 or 3 miles
Unnamed Glacier	1901	3 or 4 miles
Haenke	1905–6	6 or 7 miles
Atrevida	1905–6	8 miles
Variegated	1905–6	10 miles
Marvine	1905–6	10 miles†
Hidden	1906 or 1907	16 or 17 miles
Lucia	1909	17 or 18 miles
Nunatak	1910	20 miles

* Between Haenke and Hubbard glaciers.

† Excluding expanded lobe in Malaspina.

Prince William Sound.—Columbia Glacier advanced 600 feet between August 24, 1909, and July 4, 1910, and at least 132 feet more between the latter date and September 5, 1910. In College Fiord the Harvard, Yale, Radcliffe, Smith, Bryn Mawr, Vassar, Wellesley, and Barnard glaciers were advancing much more actively in 1910 than in 1909, and were destroying forest at their borders, as were the Meares Glacier in Unakwik Inlet, the Harriman, Baker, Roaring, and Cataract glaciers in Harriman Fiord, and the Blackstone Glacier in Blackstone Bay. Harvard glacier had advanced 100 to 150 feet, Yale 750 feet, and Harriman 300 feet between 1899 and 1910. Barry and Surprise glaciers in Harriman Fiord retreated $2\frac{1}{2}$ and $1\frac{1}{4}$ miles respectively from 1899 to 1910, different parts of the Barry retreating 500 to 1,600 feet of this distance between 1909 and 1910. Valdez and Shoup glaciers in eastern Prince William Sound and Nellie Juan Glacier in Port Nellie Juan remained unchanged from 1908 to 1910, as did Chenega, Princeton, and Tiger glaciers in Icy Bay, where there was a six or seven mile retreat between 1787 and 1908, most of it later than 1898. Portage Glacier in Passage Canal had a great advance between 1794 and 1880, filling a pass from Prince William Sound to Cook Inlet to a height of over 1,000 feet, where there was previously a low canoe portage and no glacier.

Copper River.—Miles Glacier retreated about 1,700 feet from 1900 to 1906 and readvanced 1,800 feet from 1906 to 1910. Grinnell Glacier advanced slightly between 1909 and 1910. Different parts of the front of Childs Glacier advanced 920 to 1,225 feet between 1909 and June, 1910, in midglacier, where the front is undercut by Copper River. On the north bank of the river where the margin of the glacier ends on the land and was stagnant in 1909, it advanced 1,500 to 1,600 feet up to June 10, 1910, and 204 feet more up to October 5, 1910. The glacier front developed lobes so that some parts advanced faster than others. The rates per day through the summer of 1910 were as follows:

Dates	Days	Advance in Meters		Rate per Day in Feet	
		Fastest	Average	Fastest	Average
June 10 to July 29	49	124	116	2.5	2.37
July 29 to Aug. 6	8	26	23	3.25	2.87
Aug. 6 to Aug. 11	5	41	8	8.2	1.60
Aug. 11 to Aug. 17	6	27	4	4.5	0.66
Aug. 17 to Aug. 29	12	42	19	3.5	1.58
Aug. 29 to Sept. 19	21	37	27	1.76	1.28
Sept. 19 to Oct. 5	17	13	$7\frac{1}{2}$	0.7	0.44

In midglacier there was a relative retreat of the advancing ice front from June to September, while the north border continued to advance strongly, as shown above. This retreat was due to undercuttings during the summer

rise of the river and was followed by a strong advance in late September and early October when the level of the river fell and its undercutting power was weakened. This oscillation is shown in the accompanying table.

Dates	Variation of Glacier	Stage of River
1909 to June 10, 1910	Advance, 920–1,225 ft.	Fall, 14 ft., May 6 to June 10
June 10 to Aug. 11	Retreat, 450 ft.	Rise, 6 ft.
Aug. 11 to Aug. 17	Retreat, 65 ft.	Level, about stationary
Aug. 17 to ———	Retreat continued	Rise, $1\frac{7}{10}$ ft.
——— to Oct. 5	Advance, 390 ft., plus unknown retreat above	Fall, 9 ft.

As this advance of Childs Glacier seriously threatened a $1,400,000 steel railway bridge which in October, 1910, was only 1,575 feet from the north margin of the glacier, the behavior of Childs Glacier during the winter of 1910–11, when Copper River is low and weak, will be of much interest. The diminution of movement on the north bank suggests, however, that the advance is practically over. The advance of Grinnell Glacier is also of interest, for this ice tongue occupies a strategic position with reference to the railway, which traverses its stagnant outer portion. In this portion, however, there was no disturbance in 1910, the advance affecting another part of the glacier. The Allen Glacier, whose stagnant outer portion is traversed for $5\frac{1}{2}$ miles by this railway, remained unchanged from 1909 to 1910.

It appears, therefore, that the glaciers about Prince William Sound give some indication of a general, but not very large, advance.

Correction.—In the Report on the Glaciers of the United States for 1908 (*Journal of Geology*, XVII, 671), the name "Matamaka Glacier" should have been "Matanuska Glacier."

The regular meeting of the International Committee on Glaciers took place in Stockholm on the 20th of August, 1910, in connection with the Eleventh International Geological Congress.[1] The retiring president, Professor Edouard Brückner, presented the report of the Committee to the Congress.

He called attention to the origin of the Committee, which was first appointed by the Sixth International Geological Congress in 1894, and has been collecting information regarding the variations of glaciers ever since; and emphasized the importance of the work

[1] "La Commission internationale des Glaciers au Congrès géologique international, Stockholm, août, 1910." *Zeitschrift für Gletscherkunde* (1911), V, pp. 161–76.

of Professor Finsterwalder, who, as retiring president in 1903, laid down the fundamentals of a mathematical theory of glacier variations. He then reviewed the information collected regarding the variations of glaciers. In the Alps the retreat of the glaciers continues steadily, although a few glaciers of the Oetztal and some others have made small temporary advances. The retreat has lasted for several decades. A graphic representation of the variations of 26 glaciers in the Swiss Alps, including the Mont Blanc group, shows that, for the greater number of them, the retreat has lasted since the beginning of the nineteenth century, and that the advance which occurred about 1850 was but an episode in the general retreat. Since that time the retreat has been still more marked. In the Scandinavian Alps the variations have been somewhat different; in this region an advance occurred in the beginning of the twentieth century. It began in the Jostedalsbrä and the Folgefon and progressed toward the north; but the advance was confined to the coast region and the glaciers in the mountains of central Scandinavia did not participate in it. This advance must also be looked upon as an unimportant event in the general retreat. The glaciers of the Caucasus, of the Tyan-Shan, the Altai, the Highlands of Pamir, and the Himalaya are in retreat, though here also special cases of advance have been noted. Among the glaciers of the United States and Canada the retreat is general and this is true to a still more marked extent in Alaska. Between 1892 and 1907, the retreat of the glaciers has increased the area of Glacier Bay by 19 square miles. Of great interest are the sudden remarkable advances of the glaciers of Yakutat Bay, which Professor R. S. Tarr has described and imputed to the great increase in snow-supply due to avalanches incited by the earthquakes of 1899. Professor Hauthal has described the rapid advance of the Bismarck Glacier, in South America, since the end of the last century.

Professor Kilian described the variations of glaciers in France. The importance of the water from glacial streams has led the Minister of Agriculture to give material aid to the observations of glaciers.

Professor Dr. F. W. Svenonius spoke of the difficulty of making

observations among the Swedish glaciers on account of their distance and inaccessibility, but nevertheless the Swedish Geological Survey has published a collection of six essays by the leading Swedish glacialists which give an excellent account of what is known of these glaciers.[1]

[1] Dr. Axel Hamberg has been elected an ordinary member of the Committee to represent Sweden, succeeding Dr. F. W. Svenonius, who has retired and been elected a corresponding member. Professor R. S. Tarr has also been elected a corresponding member. Two corresponding members, Mr. W. S. Vaux, Jr., and Professor E. Hagenbach-Bischoff, have died since the 1906 meeting of the Committee. The following officers were elected to serve until the next meeting of the International Congress of Geologists: Honorary President, Prince Roland Bonaparte of Paris; Active President, M. Charles Rabot of Paris; Secretary, M. Ernest Muret of Lausanne.

Petrological Abstracts and Reviews

Edited by ALBERT JOHANNSEN

Arschinow, Wladimir. "Ueber die Verwendung einer Glashalbkugel zu quantitativen optischen Untersuchungen am Polarisationsmikroskope," *Zeitschr. Kryst.*, XLVIII (1910), 225–29. Fig. 1.

A simple apparatus for making quantitative measurements by tilting a thin section under the microscope. The author claims to be able to make measurements with as great a degree of accuracy as may be made with Fedorow's or Klein's Universaltisch.

The instrument consists of a glass hemisphere, 50–60 mm. in diameter, which is centered upon the stage of the microscope and rotated by hand. The section is fastened to the flat side of the hemisphere with cedar oil or glycerin, and with the cover-glass down. The determination of planes of extinction and so on are made as with the Fedorow Universaltisch, and the angle of rotation is measured by means of two graduated metal strips, attached 90° apart, to a movable ring around the equator of the glass hemisphere, and themselves capable of being moved on pivots. By raising the tube of the microscope above these rings, the angles at which they cross may be read, and this determines the amount of rotation of the glass hemisphere. For certain measurements a small glass hemisphere, 8–15 mm. in diameter, is attached to the upper surface of the slide.

Albert Johannsen

Bastin, Edson S. "Geology of the Pegmatites and Associated Rocks of Maine," *Bull. U.S. Geol. Survey No. 445*, Washington, 1911. Pp. 152, pl. 18, figs. 8, map 1.

In this bulletin on the pegmatites of Maine, Doctor Bastin has given not only local descriptions but has made an important contribution to the general literature of the pegmatites as well. The work is divided, practically, into three parts: a general discussion of pegmatites

and in particular those of Maine, local descriptions by counties, and descriptions of the economically important minerals.

Granite-pegmatites are defined here as differing but little from the granites of the state in mineral composition, but are characterized, not necessarily by coarse, but by extreme irregularity of grain. They occur in dikes or sill-like masses, generally of sheet-like form and sometimes of considerable size. The contact with the country rock is generally sharp, indicating very little assimilation by the pegmatite even where it is of batholithic dimensions. Contact metamorphism around the pegmatites is no greater than that near granite contacts, and indicates, according to the writer, that the amount of mineralizers present was but little greater than in the latter rocks; less than ten times as great, probably. Genetically the pegmatites are related to the associated granites and are probably contemporaneous with them. Where particularly abundant, they form, apparently, the roofs above granite batholiths. An examination of the quartz grains indicates, in the coarser varieties, that the crystallization began slightly above 575° C. and ended at a lower temperature. The finer-grained varieties may have crystallized entirely above 575°.

Among the minerals of economic importance found in the Maine pegmatites are the feldspars, orthoclase and microcline rose and smoky quartz, amethyst, muscovite, tourmaline, beryl of various colors, and topaz. The occurrences, compositions, properties, and uses of these minerals are discussed.

Albert Johannsen

Couyat, J. "Les roches sodiques du désert arabique," *Comptes Rendus de l'Académie des Sciences*, CLI (1910), 1138–41.

In a region east of the Nile, near longitude 34° 18′ E., latitude 24° 40′ N., there are dikes and stocks of nepheline syenite with much variation in texture, also tinguaite and sölvsbergite. Four analyses of the syenite show SiO_2 60.1 to 56.5 per cent; Na_2O 9.0 to 10.6 per cent; K_2O 4.5 to 5.2 per cent; Fe_2O_3, FeO 3.2 to 6.1 per cent; very low MgO and CaO. In the quantitative classification the rocks are miaskoses and laurdaloses.

The syenites are related to volcanic eruptives of Cretaceous age and posterior to a series of trachytes, andesites, and basalts.

F. C. Calkins

DUPARC, L., AND PAMPHIL, G. "Sur l'issite, une nouvelle roche filonienne dans la dunite," *Comptes Rendus de l'Académie des Sciences*, CLI (1910), 1136–38.

The rocks described form dikes in massive dunites of the platinum deposits in the basin of the river Iss. They consist mainly of hornblende, with subordinate pyroxene, labradorite in some cases, magnetite, and apatite. Five analyses are given. SiO_2 ranges approximately from 33 to 47 per cent; Fe_2O_3 from 3 to 9 per cent; FeO from 14 to 9 per cent; CaO from 16 to 11 per cent; MgO from 10 to 7 per cent; total alkalies 2 to 3 per cent. In the quantitative classification, the rocks fall in auvergnose and three unnamed subrangs.

F. C. CALKINS

DUPARC, L., AND WUNDER, M. "Sur les Serpentines du Krebet-Salatim (Oural du Nord)," *Comptes Rendus de l'Académie des Sciences*, CLII (1911), 883–85.

Describes dunites and harzburgites more or less completely altered to antigorite and bastite. Five analyses of these rocks and one of the inclosed calcareous hornfels are given.

F. C. CALKINS

GRANDJEAN, F. "Sur un mesure du laminage des sédiments (calcaires et schistes) par celui de leurs cristaux clastiques de tourmaline," *Comptes Rendus de l'Académie des Sciences*, CLI (1910), 907–9.

The author finds tourmaline an unfailing constituent of shales and limestones. The crystals of this mineral in deformed rocks show a middle portion normal in color and apparently undeformed, and ragged terminal portions of paler hue. The terminal zones are considered due to elongation of the tourmaline, and their average length (about 30 measurements is ordinarily sufficient) gives a co-efficient of deformation for the rock.

F. C. CALKINS

GROTH-JACKSON. *The Optical Properties of Crystals.* New York: John Wiley & Sons, 1910. Pp. xiv+309, figs. 121, colored plates 2.

In spite of a number of good books on optical crystallography which have appeared within the past few years, no work has quite taken the

place of Groth's classical *Physikalische Krystallographie*, and it is with great pleasure that this translation of certain parts is welcomed. The only criticism that can be made is that Professor Jackson did not translate the entire work.

The translation, in general, follows the form of the original and includes all of the "Optical Properties" in Part I, with additions, here and there, from the parts in the original devoted to systematic descriptions of crystals and methods of crystal investigation. The translation seems to be good, although, in places, the sentences, closely following the German, are rather long. A slight error is introduced, on p. 15, where the number of vibrations per second of red and violet light are spoken of, by the translation of the German billion (10^{12}) as billion (10^9).

The book is well gotten up, and the line drawings, apparently from wax plates, are sharp and clear.

ALBERT JOHANNSEN

HOWE, J. ALLEN. *The Geology of Building Stones.* New York: Longmans, Green & Co.; London: Edward Arnold, 1910. 12mo, pp. viii+455, pl. 8, maps 7, figs. 31.

This work, the fourth of Arnold's Geological Series, under the general editorship of Dr. J. E. Marr, apparently is intended primarily for architects. It treats of the rock-forming minerals and the rocks in non-technical language and gives the principal properties of each. The decay of building stone is discussed, and methods of testing are described. The author says, "There is no help: sooner or later, in the course of practice, the architect or engineer will have the need of some geological knowledge forced upon him." If the little knowledge is not a dangerous thing, this book may serve a useful purpose.

ALBERT JOHANNSEN

LACROIX, A. "Le cortège filonien des péridotites de la Nouvelle Calédonie," *Comptes Rendus de l'Académie des Sciences*, CLII (1911), 816–22.

The peridotites of Nouvelle Calédonie are cut by narrow dikes forming a gabbroic and a dioritic series. In both, gradations can be traced between a leucocratic extreme (anorthosite) and a melanocratic extreme, (pyroxenite or hornblendite). Nine analyses are given which prove that six of the rocks fall into previously unnamed subdivisions of the

quantitative classification. These are: Ouenose (III. 5. 5. 4–5); Caledonose (I. 5. 5. 4–5); Thiose (IV. 1[2]. 1[2]. 2); Naketose (IV. 2[3]. 1[3]. 2); Koghose (III. 4. 4. 4–5).

In the gabbroic series, SiO_2, Al_2O_3, and CaO increase together, while FeO and MgO decrease. Because of the basicity of the feldspars the most feldspathic phase is the poorest in SiO_2. In the dioritic series, the proportion of lime is nearly constant, silica varies irregularly, Al_2O_3 and alkalies increase with the feldspar content.

There are also dikes composed almost wholly of magnesiochromite; these locally contain chrome-bearing diopside and bronzite, and are associated with anorthosites.

F. C. CALKINS

LEISS, C. "Neues Mikroskop Modell VI*b* für krystallographische und petrographische Studien," *Zeitschr. Kryst.*, XLVIII (1910), 240–42. Fig. 1.

A large microscope similar in construction to the Hirschwald microscope (Fuess VI*a*). It differs, however, in having an Abbe condenser and Ahrens polarizer, and a large, flat micrometer stage. Like the VI*a* microscope, the upper and lower nicols can be rotated simultaneously. This does away with the cap nicol and permits the use of a large tube, giving an extra large field.

ALBERT JOHANNSEN

SKEATS, ERNEST W. "The Volcanic Rocks of Victoria," *Australian Association for the Advancement of Science*, 1909, 173–235. Pl. 4, numerous analyses.

This paper was read as the Presidential Address, Section C, of the Australian Association for the Advancement of Science. It contains a summary of the present knowledge of the Victorian volcanic rocks and has appended a bibliography of 268 items, dealing wholly, or in part, with these rocks. The geographical distribution is shown on a map and the geological range was determined to be from Basal Ordovician (?) to recent. Petrographically the rocks are rhyolites, dacites, basalts, quartz porphyries, granite porphyries, diabases, serpentines, quartz keratophyres, melaphyres, sölvsbergites, limburgites, and the new rocks anorthoclase trachyte, anorthoclase-olivine trachyte, olivine-anorthoclase basalt, olivine-anorthoclase andesite, and macedonite. Petrographical descriptions, not as complete as might be desired, espe-

cially those dealing with new types, are given, and the geographical and geological relations are shown. The new rock terms proposed are:

Anorthoclase trachyte.—This type was previously described by Professor Gregory as trachyphonolite. As described by Skeats, in a corrected copy of his paper, it is "a dark-greenish rock. Large phenocrysts of anorthoclase are numerous. The ground mass has sometimes a fluidal arrangement of laths of anorthoclase, in other cases the crystals are stouter and the structure orthophyric. Small crystals of aegirine are scattered through the rock, a little green glass, a few sections of nosean, ilmenite, and occasionally apatite are also present." From the description it does not appear that any other feldspar occurs, although the statement, in another place, that "anorthoclase is the dominant felspar," suggests that another is present.

Anorthoclase-olivine trachyte.—Spoken of as "more basic than the rock just described." It resembles the former rock but contains, in addition, more or less olivine.

Olivine-anorthoclase basalt.—"A still less acid type. . . . . It differs mainly from the last type in the greater abundance of olivine and less frequent anorthoclase." In the opinion of the reviewer this description would hardly justify the use of the term basalt.

Macedonite is a non-porphyritic, basaltic-looking rock and in the annotated copy is said to "consist largely of minute felspars, a colourless to green interstitial mineral, either glass or chlorite, serpentine or chlorite pseudomorphs after olivine, some light-brown biotite and purplish, fibrous apatite prisms. Octahedra of perofskite occur, some of which are opaque, others of a dark grayish-green colour. The exact relations of this rock are difficult to determine. Chemically it is in some respects intermediate between the tephrites and the orthoclase basalts, but mineralogically it is quite distinct. Its nearest relations are with the mugearites, from which it differs in the ratio of soda to potash and in the small amount of olivine present." The writer does not say what kind of feldspar is present, but if the analysis is computed in the Quantitative System of C.I.P.W., the norm shows orthoclase, 20.02 per cent, albite, 29.87 per cent, and anorthite, 18.63 per cent. As computed by the reviewer the rock is a Shoshonose.

Olivine-anorthoclase andesite.—This is a porphyritic, subsiliceous andesite. It contains lath-shaped plagioclase and granular or ophitic augite, magnetite, and olivine as its normal constituents. Corroded phenocrysts of anorthoclase occur and connect this type with the alkali rocks.

While exact and detailed descriptions may seem tedious in an address, it would be desirable in printed descriptions of new types of rocks that they be made as complete as possible and that the relative amounts of the different constituents be stated. For such rocks, clear-cut definitions should be given.

The paper is a well-written summary of what is known of the volcanic rocks of Victoria, and one is always thankful for contributions containing careful analyses and complete bibliographies.

ALBERT JOHANNSEN

WATSON, THOMAS L. "Intermediate (Quartz Monzonitic) Character of the Central and Southern Appalachian Granites," *Bull. Phil. Soc., Univ. Va.*, I (1910), 1–39.

By comparing the analyses of granites from different parts of the Appalachian region, the author finds that they are, in general, of monzonitic character, the soda being molecularly equal to or greater than potash. Comparing the western granites with the Appalachian rocks, he finds that "the eastern type shows stronger granite affinities and the western type stronger quartz diorite affinities." In general the granites of the eastern region are of similar composition, containing acid oligoclase and some albite in addition to potash feldspar; the ratio averaging 1.88 to 1. All of the granites, from Alabama to New England, as well as the subsilicic gabbros, diabases, pyroxenites, and peridotites, "have been derived from a common parent body of magma intruded, in most cases, at different times," says the writer. The age of the massive granite is stated to be early or later Paleozoic, while the granite-gneisses (gneissoid-granites) are pre-Cambrian.

Numerous analyses, all of them partial, are given.

ALBERT JOHANNSEN

Reviews

The Coming of Evolution: the Story of a Great Revolution. By John W. Judd. London and Edinburgh: The Cambridge University Press, 1910. Pp. 171.

The numerous addresses which were delivered in various parts of the world in connection with the recent Darwin Centenary seem to have had for their common burden the revivification of all science by the revolution which Darwin introduced in the biological field. Seldom has it been pointed out, and never before in so convincing a manner, that the acceptance of evolution for the organic world was a direct outgrowth of its demonstration in the field of geological science. It was the publication by Sir Charles Lyell in 1830–33 of his *Principles of Geology*, giving currency to continuity or uniformitarianism in the realm of inorganic nature, that laid the foundations of modern geology and paved the way for modern biology as well. Darwin was first a geologist, and his great debt to Lyell he was ever ready to acknowledge. Says Professor Judd: "Were I to assert that if the *Principles of Geology* had not been written, we should never have had the *Origin of Species*, I think I should not be going too far; at all events, I can safely assert, from several conversations I had with Darwin, that he would have most unhesitatingly agreed in that opinion."

Huxley has given his verdict that "consistent uniformitarianism postulates evolution as much in the organic as in the inorganic world." In dedicating the second edition of his favorite work, the *Narrative of the Voyage of the Beagle*, Darwin wrote: "To Charles Lyell, Esq., F.R.S., this second edition is dedicated with grateful pleasure, as an acknowledgment that the chief part of whatever scientific merit this journal and the other works of the author may possess, has been derived from studying the well-known admirable *Principles of Geology*." To Leonard Horner he wrote: "I always feel as if my books came half out of Lyell's brain." In the *Origin of Species* Darwin refers to "Lyell's grand work on the *Principles of Geology*, which the future historian will recognize as having produced a revolution in Natural Science."

The *Coming of Evolution*, first in the geological and later in the biological field, has fortunately now been told by a veteran geologist

and one who enjoyed the friendship of all the great leaders in the movement—Huxley, Hooker, Scrope, Wallace, Lyell, and Darwin. Of those who were on terms of affectionate intimacy with both Charles Lyell and Charles Darwin, Professor Judd is perhaps the unique survivor. It is this intimate personal relationship to the chief actors in the great drama, combined with a peculiarly simple and graceful style of writing, which makes the fascination of this little book. At every turn of the page the reader is surprised by the reference to some remark of Lyell, Darwin, or Huxley, which sheds a flood of light upon the psychology of the whole movement.

The great success of the *Principles of Geology* seems in some measure to have been due to Lyell's study of the causes of failure of the *Theory of the Earth* by the illustrious Hutton, whose death occurred the year Lyell was born. On the basis of his extended observations, Hutton as early as 1785 wrote the oft-quoted, "I can see no evidence of a beginning, and no prospect of an end," a blunt statement which antagonized the church, then especially active in hunting heresy. Furthermore, his work was written in a heavy and cumbrous style. Profiting by this example, Lyell schooled himself in graceful, accurate, and forceful expression, and at some pains and with favoring fortune was able to avoid a clash with the established church. In no small measure this was due to an extremely favorable notice of his *Principles* in the *Quarterly Review*, then the champion of orthodoxy. With the geologists of the official Geological Survey, Lyell was less fortunate, and in spite of the general popularity of his epoch-making ideas, they were bitterly fought by the official class of geologists and only slowly won support in this field. Professor Judd's fascinating story of the coming of evolution should find a wide circle of readers, especially among students of natural science.

W. H. H.

North American Index Fossils: Invertebrates. By Amadeus W. Grabau and Hervey Woodburn Shimer. Vols. I and II. New York: A. G. Seiler & Co., 1909 and 1910.

With the rapid accumulation of special literature in the field of systematic paleontology, and the growing inaccessibility of many of the older works except to those having access to large libraries, it is ever becoming more and more difficult for the non-specialist to identify his species of fossils. At the same time, with the growing refinements in stratigraphy, it is ever becoming more important to the stratigraphic

geologist to give close attention to the fossil faunas present in his rock formations, and to have accurate identifications of his fossils. It is, therefore, a pleasure to notice the appearance of such a work as *North American Index Fossils* by Grabau and Shimer.

In the two volumes of 853 and 909 pages respectively which comprise this work, approximately 1,500 genera and 4,000 species are defined, a large portion of the species being accompanied by illustrations incorporated in the text, the figures being copied from various sources for which credit is always given. The species selected for definition have been chosen to include, first, those most characteristic of important stratigraphic divisions, i.e., those of wide geographic and limited stratigraphic range; secondly, those having a wide geographic distribution even though their stratigraphic range is also great, i.e., the very common American species; and thirdly, forms which it is important that students of structural and anatomical paleontology should understand. The species are arranged chronologically under their respective genera, the genera being arranged systematically under their proper families, orders, classes, and phyla. Brief discussions of the structural features of each phylum and class are included, but except in the case of the Arthropoda, no definitions of subclasses or orders are given. Under each class is given a brief bibliography of the more important literature, which will be of use to such as wish to carry their studies beyond the limits of the work. A decided innovation is the inclusion of extensive analytical keys to the genera under each of the classes. These keys are probably the most elaborate ever attempted for fossil invertebrates, and will doubtless be of much value to those using the books, although it must be kept in mind always that such keys can never be of so great utility in the classification of fossils, which are frequently if not usually represented by more or less incomplete specimens, as in the classification of living organisms.

The closing pages of the second volume are given up to a series of appendices, as follows: A, Summary of North American Stratigraphy, Tables of Geological Formations (50 pages); B, Faunal Summary, Tables Showing Distribution of Species Described (50 pages); C, General Bibliography of North American Invertebrate Index Fossils and Fossil Faunas (1832–1909) (89 pages). In this bibliography the titles are arranged in accordance with the geological systems, those for each system being grouped geographically; D, Hints for Collecting and Preparing Fossil Invertebrates (16 pages); E, Glossary (36 pages) and General Index.

These volumes have been prepared primarily for the non-specialist, more especially for workers in stratigraphic geology who have not received special training in paleontology. For such workers, as well as for geological students in colleges and universities, and for amateur paleontologists and collectors of fossils, the volumes will prove to be of great value.

S. W.

Olenellus and Other Genera of the Mesonacidae. By CHARLES D. WALCOTT, Smithsonian Miscellaneous Collections, LV, No. 6.

In his memoir on the *Olenellus* fauna, published in the *Tenth Annual Report of the United States Geological Survey*, in 1891, Walcott recognized seven American and three foreign species of *Olenellus*, included in three subgeneric groups, *Olenellus* proper, *Mesonacis*, and *Holmia*. The present contribution represents the advance of knowledge concerning this highly interesting group of Cambrian trilobites since the appearance of the earlier memoir. Thirty-four species, including two varieties, are now recognized, besides two undetermined ones, thirty-six in all, arranged in ten groups which are given full generic rank, the entire group of forms being elevated to a family under the name *Mesonacidae*. Twenty-four of these forms are American and twelve foreign, the foreign representatives being known only from northwestern Europe.

With the restriction of the genus *Olenellus* to include only one group of these species, it comes about that this genus is no longer characteristic of the entire Lower Cambrian, as has commonly been assumed since the publication of the earlier memoir, but occurs only in the uppermost division of the series. In the present paper the Lower Cambrian is divided into four faunal zones, designated, beginning with the oldest, (1) *Nevadia* zone, (2) *Elliptocephala* zone, (3) *Callavia* zone, (4) *Olenellus* zone, each named from the leading Mesonacid genus present in the fauna. Aside from these four index genera the following are recognized: *Mesonacis* Walcott, *Holmia* Matthew, *Wanneria* n. gen., *Paedeumias* n. gen., *Peachella* n. gen., and *Olenelloides* Peach.

In their genetic relations the genera discussed are assumed to diverge along two lines from the primitive *Nevadia*. The one line includes *Callavia*, *Holmia*, and *Wanneria* in order, the last of which is supposed to give origin to *Paradoxides* of the Middle Cambrian. The second line of descent springing from *Nevadia* includes *Mesonacis*, *Elliptocephala*, *Paedeumias*, and *Olenellus* in serial order, the last of these genera giving origin on the one hand to *Peachella* and on the other hand to *Olenelloides*.

Some question may be raised, perhaps, as to the legitimacy of the assumption of such a phylogenetic origin of *Paradoxides*. The most diagnostic character of the entire family *Mesonacidae* is the absence of a facial suture, although well-developed compound eyes are present. Elsewhere among the trilobites, where the free and fixed cheeks have become anchylosed, with the consequent disappearance of the facial suture, as, for instance, in the Devonian genus *Phacops*, this character has appeared at the termination of a long phylogenetic line in which all the earlier members possess functional facial sutures. The facial suture is so characteristic of every order and every family of trilobites, save the *Mesonacidae*, that one is forced to the assumption that it was a character of the primitive stock from which all have sprung. It therefore seems necessary to assume that the ancestors of the *Mesonacidae* possessed a functional facial suture, and that the absence of this character in this group of genera is indicative of its terminal position in a long phylogenetic line whose pre-Cambrian history is unknown to us. Since such a character when once lost cannot be restored again, it would follow that *Paradoxides* with its functional facial suture could not have originated from any member of the *Mesonacidae*. Might it not be assumed that *Paradoxides* arose from a totally distinct phylogenetic line in a different early Cambrian biologic province, perhaps southern Europe, and later migrated into the North Atlantic province where it occurs in strata generally younger than those bearing the Mesonacid faunas? Under such an interpretation it would be necessary to grant that somewhere *Paradoxides* may have been contemporaneous with at least a portion of the Mesonacid faunas in North America, and this contemporaneity may even have extended to the North American shore of the North Atlantic basin.

The paper adds much to our knowledge of these very ancient faunas of the earth, and the author is to be congratulated upon the success of his most persistent search for these rare fossil forms. Not the least attractive portion of the paper are the twenty-two beautifully executed half-tone plates.

S. W.

Elements of Geology. By ELIOT BLACKWELDER AND HARLAN H. BARROWS. Pp. 475; figs. 485; pls. 16. New York: American Book Co., 1911.

This is not a manual or reference book, but an elementary textbook intended primarily for use by young students in the high schools, acade-

mies, and institutions of similar grade. The book was written in the belief that it is the function of a text as well as the duty of a teacher to develop in the student the power to reason. This spirit pervades the work throughout.

The method is essentially analytical and the text explanatory rather than descriptive. Abundant use is made of questions which are ingeniously devised to guide the student's mental operations and to lead him unconsciously through certain desired chains of reasoning. Many of the questions are inserted in the text—a practice which makes the student stop and think and, by causing him to tie his ideas together, incidentally and unconsciously brings him to see the interrelation of the different geologic agents and processes.

The treatment throughout indicates a continuous desire to prevent the student from forming hard-and-fast conceptions of processes and geologic features that are necessarily often variable. There is a steady determination to compel the student to maintain a critical open mind and at the same time to draw close distinctions in the use of variable terms, as in the relative heights of hills and mountains and of plains and plateaus. Sometimes, however, this most laudable endeavor threatens to overstep itself and lumber up the text with hypercritical qualifications. In an elementary textbook where space is severely limited unessential discriminations crowd out more weighty matter, while the student on his part may come to give too much thought to precision in little things at the expense of a grasp of great things. But this is only another item in the ever-present question of where to draw the line.

The text is clear, direct, and well written. In some cases, as in chap. i, the opening paragraph is a bit wobbly, but when the initial groping for just the right line is past and the topic is well under way, the chain of ideas, like the language, flows evenly and gracefully along without effort.

Poise and balance characterize the treatment of facts and principles. The essential features are treated clearly though concisely, and the minor features are subordinated or left out where their omission does not weaken the presentation of the main topics. Unessential facts have been carefully pruned. Keen discrimination is apparent here.

The departure of the authors from current practice in the arrangement of material will be most conspicuously seen in the omission of separate chapters on vulcanism and earthquakes. This was done in the belief that volcanoes and especially earthquakes are exceptional

and local phenomena and that although spectacular and ever interesting to the popular mind, they are not entitled to the same space in such a work as are the more general geologic processes. The main features of vulcanism and volcanic rocks are, however, quite adequately treated in the chapter on the composition of the earth, while volcanic mountains as surface features appear in the very excellent chapter entitled "The Great Relief Features of the Land."

The proper handling of historical geology in brief space is a difficult task. There is a great deal of ground to be covered and a great mass of material to be judiciously picked over. Unless the work is well done, the residue left is apt to be a dry bone skeleton with the flesh and blood largely gone. In the historical portion of this work the salient and vital points are made to stand out clearly. This is particularly true of the life history. In part this is secured by a sprightly use of paragraph headings to feature the various vicissitudes through which life forms have passed in their long history. With these in mind, the significance of the discussion is more readily grasped and the details are more easily retained.

The authors have treated the Tertiary as a "Period," giving it the same rank in the geologic time scale as they do the Comanche or the Cretaceous. After stating that it is divided into the Eocene, Miocene, and Pliocene epochs, the Tertiary is discussed largely as a unit. The Tertiary presents many rich problems for advanced students, especially its mammalian evolution and its diastrophism, but these are perhaps beyond the reach of a beginning class. The authors, believing that the points of newness or striking facts are largely over by the time the Tertiary is reached, have apparently thought it best to curtail the treatment and advance rapidly to the close of the history.

A feature which cannot be too highly commended is the extensive use of three-dimension diagrams to portray the operation of geologic processes. This, in the reviewer's opinion, is much more expressive than the ordinary style. The set of three block diagrams on p. 146 which picture the successive development of youthful, mature, and old topography, illustrating not only the surface development of the streams but the simultaneous lowering of the land toward peneplanation, shows the possibilities of the method.

By reducing the size of the illustrations, a very large number have been successfully introduced and add very greatly to the effectiveness and attractiveness of the book. It is a veritable picture book with most of the pictures new to geologic readers.

Finally it may be said that the general scheme and mode of treatment of the book follow the lead of the comprehensive treatise of Chamberlin and Salisbury, and the fundamental views which give distinctive character to that work find reflection in this.

R. T. C.

Geology of the Kiruna District (2). Igneous Rocks and Iron Ore of Kürunavaara Luossovaara and Tualluvaara. Academical Dissertation by Per A. Geijer, for the degree of Doctor of Philosophy. By the permission of the philosophical faculty of the University of Upsala. Stockholm, 1910. Pp. 278; 2 geologic maps.

The district is in northern Lapland. The rocks, which are generally regarded as pre-Cambrian, include greenstones, conglomerates, syenite porphyries, magnetite ores, quartz porphyry, phyllites, sandstones, etc. They are strongly folded and in general stand nearly vertical but otherwise do not show pronounced metamorphism. The textures are well preserved. A typical ore body is the one of Kürunavaara which forms the backbone of a mountain about 748 meters high. This ore body is over 5 kilometers long and some 96 meters wide. Other ore bodies are somewhat smaller. The ore zone is included between quartz porphyry and syenite porphyry. The minerals of the ore are magnetite, hematite (subordinate), fluor-apatite, augite, amphibole, biotite, titanite, tourmaline, zircon, etc. Generally there is enough apatite to place the ore above the Bessemer limit.

The ore minerals are intergrown like those of an igneous rock and contacts between ore and country rock are in places gradational. All of the minerals of the ore except tourmaline are primary constituents of igneous rocks near by. Rock textures indicate that the ore mass has crystallized quite in the same way as an igneous rock—these include trachytoidal flow structure, skeleton forms of magnetite, and the ophitic distribution of augite. The ores are believed to be of magmatic origin and the writer is inclined to the view that the associated syenites are effusive in character. He does not agree with De Launey, who held that the ores were deposited at the surface from gases and hot solutions by pneumatolytic-sedimentary processes. The writer does not feel sure as to the nature of the differentiation processes which have resulted in the product, but does believe that such an origin is proven.

W. H. E.

The Edmonton Coal Field, Alberta. By D. B. DOWLING. Canada Department of Mines, Geological Survey Branch, 1910. 59 pages, 2 maps.

The area primarily considered is on the Saskatchewan River, in and near Edmonton, but a short discussion of the surrounding coal fields is included. The coal is lignitic or semi-bituminous, and occurs near the middle and at the top of 700 feet of brackish water deposits, the Edmonton formation, at the top of the Cretaceous, and in Tertiary sandstone above. The lower horizon, the Clover Bar seam, is worked at Edmonton, and 80,000,000 tons are estimated to be available in an area of 14 square miles.

W. A. T.

Preliminary Memoir on the Lewes and Nordenskiold Rivers Coal District, Yukon Territory. By D. D. CAIRNES. Canada Department of Mines, Geological Survey Branch, 1910. 70 pages, 2 maps.

The development of the Whitehorse copper deposits was the incentive for the investigation of the available coal resources in the district described in this report. The important formations of the district are the Braeburn limestone (carboniferous?), the Laberge series, conglomerates, shales, sandstones, etc., and Tantalus conglomerates, Jurasso-Cretaceous. Tertiary volcanics have broken through these formations and overflowed them in many places. Important coking coal seams occur in the Tantalus conglomerates and near the top of the Laberge series, but they are available only near the navigable water, such as the Lewes River and Lake Laberge.

W. A. T.

Geology of the Nipigon Basin, Ontario. By A. W. G. WILSON. Canada Department of Mines, Geological Survey Branch, 1910. 152 pages, 1 map.

The region covered by this excellent report is underlain mainly by Laurentian gneisses and granites, but scattered over it are areas of greenstones and green schists, called Keewatin. A few bands of Lower Huronian rocks are known. Lying on the eroded surface of these formations is a series of conglomerates, sandstones, shales, and dolomitic limestones classed as Keweenawan, although the author believes

they might be younger than pre-Cambrian. The youngest rock is a diabase, which occurs as intrusive sheets and flows. The evidence for and against the diabase occurring as a volcanic flow is fully discussed, the conclusion being that as now known they are basal residuals of former extensive flows.

The glacial geology is briefly discussed, the author concluding that ice erosion was very limited, except locally. The physiographic features are considered, also the economic geology, but no deposits of any value are known.

W. A. T.

The Geology and Ore Deposits of the West Pilbara Goldfield. By H. P. Woodward. Bull. No. 41, Western Australia Geological Survey. Pp. 142; 5 geological maps; 1 mining plan; 25 figs.

The first part of the bulletin is devoted to a general discussion of the physiography, geology, and petrography of the district, which occupies the triangular portion of the northwest division of the state included between the Fortescue and Yule rivers. The southern part of the area is a high tableland which drops abruptly to the wide, low coastal plain forming the northern part.

The oldest rocks in the region are metamorphosed sedimentaries—clay slates and shales—that have been intruded successively by dolerite, gabbro, and granite. The last is thought to have altered some of the clay slates and dolerites to crystalline schists. A period of subsidence was accompanied by an outburst of volcanic activity in the form of fissure eruptions of very fluid basic lava. Subsidence continued, and marine beds are found above the last lava flow. Re-elevation and denudation have given rise to the present topography. The various formations are described in some detail, and petrological notes on seventy specimens are appended.

The second part of the bulletin is devoted to a more detailed description of the country and the mining centers visited. The lodes are most frequently found in the altered sedimentaries. They carry, in addition to gold, varying amounts of pyrite, chalcopyrite, and galena. Little evidence regarding the genesis of the lodes is presented. Much of the material is of greater interest to the engineer and the investor than to the geologist.

A. D. B.

A Review of Mining Operations in the State of South Australia during the Half-Year Ended December 31, 1910. No. 13. Issued by T. Duffield, Secretary for Mines. Adelaide, 1911. Pp. 34; pls. 2.

This paper gives statistics on leases, claims, subsidies, men employed, prices, and various industrial and technical features of the mining districts of South Australia. Notes on recent development work, including assays of samples and amount of boring, tunneling, etc., done on various properties make up a large part of the review.

An interesting method of draining the southeastern district has been approved by the government geologist. The plan is to sink borings or shafts into a porous stratum underlying the swamp areas and allow the water to escape through underground channels, saving the expense of extensive ditches necessary for surface drainage. Small areas have been drained into natural sink holes with very encouraging results.

A. D. B.

Report on the Iron Ore Deposits along the Ottawa (Quebec Side) and Gatineau Rivers. By Fritz Cirkel. Canada Department of Mines, Mines Branch. No. 23, 1909. Pp. 147; plates 5; maps 2.

The area covered by this report is about 900 square miles, extending from Ottawa 100 miles up the Ottawa River and 83 miles up the Gatineau. Deposits of magnetite and hematite ore have been known for over sixty years and attempts have been made at various times to develop them, but without success. The present report is the result of a comprehensive examination of the region to determine the possibilities of development of the deposits. One important factor is the available water power which is described in detail in the appendix.

E. R. L.

Maryland Geological Survey, Vol. VIII, 1909. William Bullock Clark, State Geologist.

This volume, which is entirely economic in its nature, contains the following reports: Part I, "Second Report on State Highway Construction," by Walter Wilson Crosby, pp. 29–95; Part II, "Maryland Mineral Industries, 1896–1907," by Wm. Bullock Clark and Edward B. Mathews, pp. 99–223; Part III, "Report on the Limestones of Maryland with Special Reference to their Use in the Manufacture of Lime

and Cement," by Edward Bennett Mathews and John Sharshall Grasty, pp. 225–477.

E. R. L.

Missouri Bureau of Geology and Mines. Biennial Report of the State Geologist for the Years 1909 and 1910. By H. A. BUEHLER AND OTHERS.

The report contains a summary of the present and proposed work of the bureau and the following chapters descriptive of work now in progress: "The Principal Coal Fields of Northern Missouri," by Henry Hinds, pp. 26–35; "Reconnaissance Work," by V. H. Hughes, pp. 36–54; and "The Geology of the Newburg Area," by Wallace Lee, pp. 55–63.

E. R. L.

Mississippi State Geological Survey, 1907. ALBERT F. CRIDER, Director.

The volume contains the following reports: Bulletin No. I, "Cement and Portland Cement Materials of Mississippi," by Albert F. Crider, pp. 73; Bulletin No. II, "Clays of Mississippi, Part 1, Brick Clays and Clay Industry of Northern Mississippi," by William N. Logan, pp. 255; Bulletin No. III, "The Lignite of Mississippi," by Calvin S. Brown, pp. 71.

E. R. L.

The Geology of the Whatatutu Subdivision, Raukumara Division, Poverty Bay. By JAMES HENRY ADAMS. New Zealand Geological Survey, Bulletin No. 9 (New Series). Wellington, 1910. Pp. 48; maps 5; plates 3.

The Raukumara division lies on the eastern side of the North Island of New Zealand and consists of a series of rolling ridges of moderate height separated by deeply cut river valleys. The rocks belong chiefly to the Whatatutu series which are upper Miocene in age and which are folded into irregular anticlines and synclines. Indications of oil have been found at various points within the region and the object of the survey was to obtain information as to the possibilities of development. With this end in view the anticlines and synclines were mapped and described with considerable care. Fossils are abundant in some localities but have received little attention in this report.

E. R. L.

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PRELIMINARY STATEMENT CONCERNING A NEW SYSTEM OF QUATERNARY LAKES IN THE MISSISSIPPI BASIN[1]

EUGENE WESLEY SHAW
U.S. Geological Survey

It is a significant fact that in but few places do the Mississippi and Ohio rivers flow on consolidated rock. Throughout most of their courses they flow over bodies of silt, sand, and gravel 50–100 feet in thickness. The lower half or third of each tributary also flows over a thick unconsolidated mass, which is similar to those on the larger streams, except that in general it is less coarse. For examples, the Wisconsin River in southwestern Wisconsin is working 50 feet or more above a hard rock channel; Big Muddy River in southern Illinois flows between mud banks in a broad, shallow valley with a buried channel 40 feet below; and away east in Pennsylvania the Monongahela does not flow over bed-rock at any point within the limits of the state. Thus, not only the valleys of the Mississippi and Ohio, but the lower part of almost every tributary valley in the northeast central states, and probably in a considerably larger territory, is partly filled with loose sediment, and in Illinois, Indiana, and Kentucky the filling on the tributary streams consists largely of clay, a brief description and interpretation of which are the objects of the present paper.

[1] Published by permission of the Director of the U.S. Geological Survey, Washington, D.C. A more complete description is to be published by the Ill. Geological Survey.

The upper surface of the clay forms a terrace which is generally so broad and so low that it is scarcely perceptible, though it is commonly separated from the flood-plain by a low scarp. This terrace is almost perfectly horizontal, and since the flood-plain rises up stream the terrace and flood-plain finally merge. However, since the flood-plain itself on the tributaries is nearly horizontal (for the streams have but little fall) the flood-plain and terrace on some rivers are distinct for 40 miles or more, although vertically they are almost nowhere more than 40 feet apart.

Another characteristic of these valleys is that in places they anastomose. Many valley floors connect through divides with neighboring valley floors. Some of the connecting parts are broad and resemble bays in the sea; others are narrow and strait-like; and the severed parts of the divide are massive. In many places the flat valley floor surrounds hills that stand up sharply like islands. These features of the lower parts of valleys tributary to the Mississippi and Ohio—the broad bottoms in hilly country, and the irregularly branching valleys—point toward valley filling. And well-sections and exposures support this indication, showing that bed-rock is far below the present streams.

Detailed description of the clay.—The clay varies from greenish-gray to purplish-gray in color and from medium plasticity to "gumbo." The lower part is evenly stratified and in places finely laminated. The upper part has less distinct stratification and is characterized by irregular concretionary masses of lime. Around the border and in the up-stream parts of the deposit there are lenses of fine sand, but considering the formation as a whole, sand forms a remarkably small part. With the exception of the concretionary lime, some particles of which are as small as sand grains, most of the deposit is without perceptible grit. In ground plan the bodies of clay are very irregular and even anastomosing—shapes that would be expected of valley fills in a country of medium to low relief (see Fig. 1). The surface of the clay in each valley is horizontal and lies from 5 to 75 feet above low water. But the altitude varies from valley to valley. Near Cairo the surface of the clay is 345 feet above sea; at Galena, Illinois, 400 miles up the Mississippi, it is 650 feet; and there is a corresponding

increase in altitude up the Ohio. Thus, although the deposit along each tributary and its branches is usually isolated and lies at a different altitude from that on every other stream, the different bodies have such a regular arrangement and have so many characters in common that there can be little question but that they are closely related, and they appear to be in large part lake deposits, but in smaller part stream deposits, so that they may be referred to as fluvio-lacustrine.

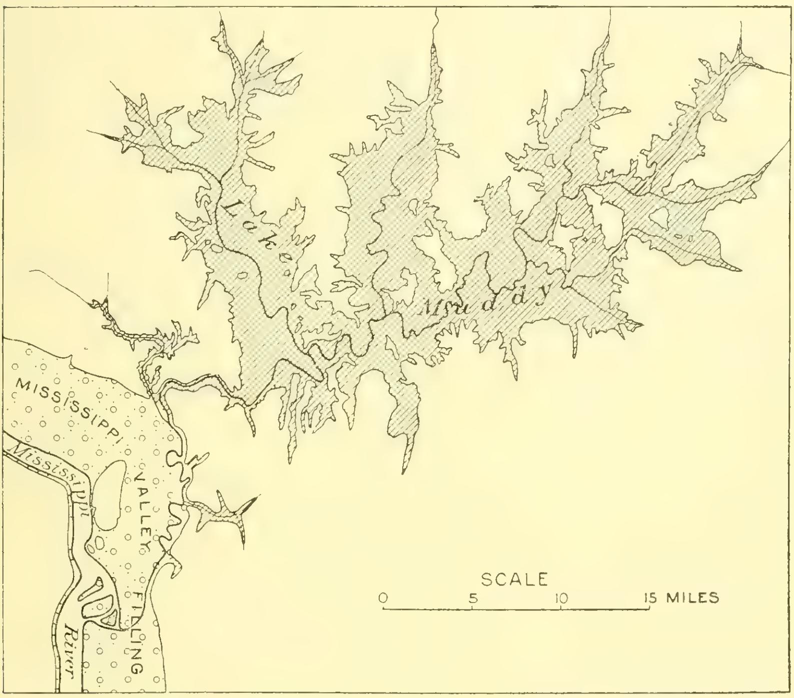

FIG. 1.—Lake Muddy, in southern Illinois. One of a series of lakes, now extinct, caused by a rapidly growing valley filling on the Mississippi and certain other streams, the filling forming a dam across the mouths of tributaries. The lakes stood at different altitudes, being controlled by the altitude of the Mississippi at their various outlets; each was in a continual state of fluctuation, the position of its surface at any moment being controlled by the stage of the Mississippi, and for a part of the time each was intermittent. The narrow part of Lake Muddy near the outlet was in a narrow, high-walled part of the valley, due to uplifted hard rocks. With the approach of every flood on the Mississippi water gushed up through the narrow part of the lake to the broader inland, a part carrying with it fine sand which, with interbedded lake silt, formed a delta at the *lower end* of the lake, fronting *toward the head* of the lake.

Shore features were generally poorly developed, though 12–15 miles northeast of Madisonville, Kentucky, 60 miles by water from the Ohio River, there are beautifully developed and well-preserved beach-ridges. These ridges are very symmetrical, being 20–50 feet wide, and 8 to 10 feet high (see Fig. 2). They are composed of sand and fine gravel and are situated across the mouths of small tributary valleys. The reason for the excellent development of gravel ridges at this place is the generous available supply of loosely cemented conglomerate, probably Late Tertiary in age, composed largely of well-rounded quartz and flint pebbles. Elsewhere there was not a large amount of well-rounded pebbles within reach of the lake and so far no other well-developed ridges have been found. At numerous places where the bank of the lake was easily eroded there is some suggestion of wave cutting, but the evidence has been almost obliterated by recent erosion. One reason for the general poor development of shore features is that owing to the rise and fall of the rivers the lakes were continually fluctuating and were intermittent for a part of the period of their existence. Thus, particularly in districts of low relief, the shores of the lakes did not stand in one position long enough to develop shore features.

Good collections of fossils were obtained, the fauna consisting of nearly a score of species of gastropods and lamellibranches, and undoubtedly many more species, including perhaps vertebrate and plant remains, might be found. Most of the forms collected inhabit lagoons and the quiet parts of streams. One of them (Campeloma) is a scavenger living in decaying animal matter. Others frequent lily ponds. Some, such as Vertigo, are northern forms, being found at present from Wisconsin northward.

The lime masses are probably secretions of blue-green algae, though at present they show little organic structure. They are more abundant in the thinner parts of the formation, and this may be correlated with the fact that lime-secreting algae flourish in very shallow or intermittent waters.

Previous work.—Bodies of this clay have been regarded as glacial drift; a lowland phase of the loess; an old normal flood-plain deposit; a back-water deposit from glacial floods on the larger

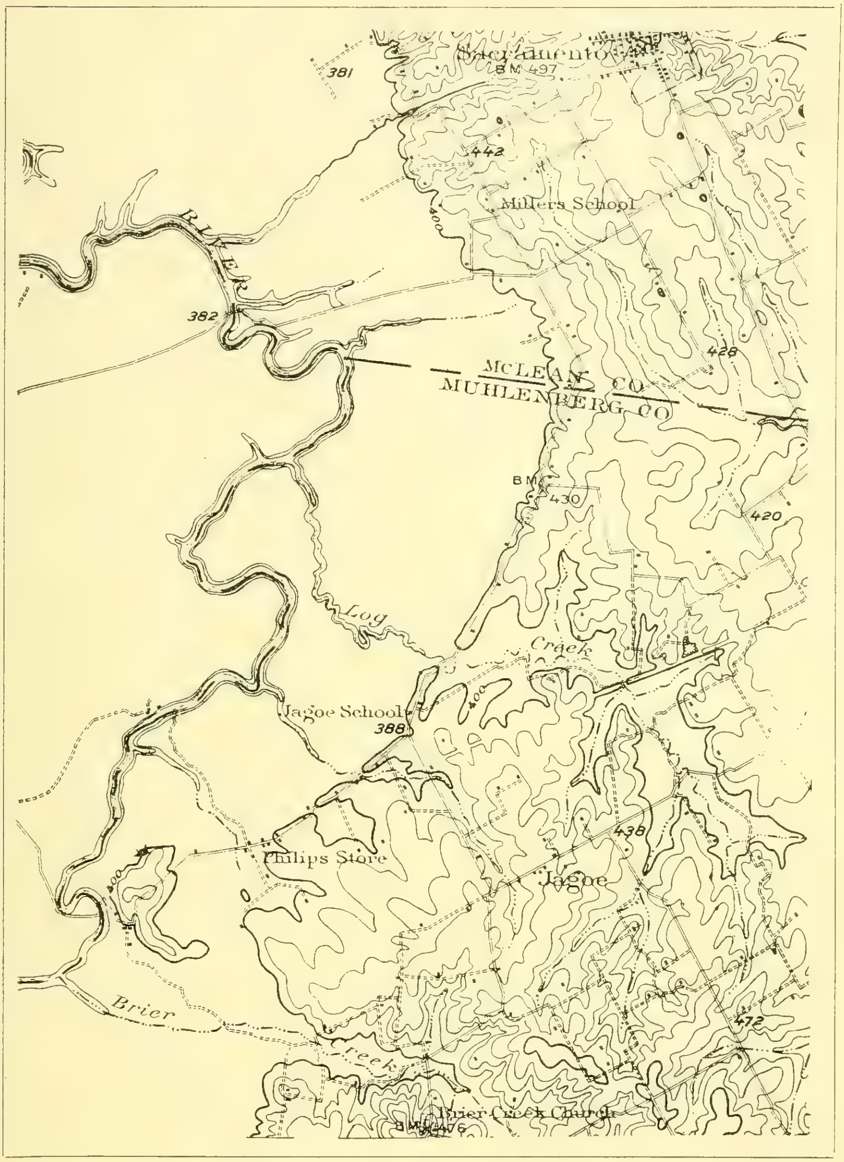

FIG. 2.—Part of Madisonville, Ky., topog. sheet, U.S. Geol. Survey, showing beach of extinct Green Lake (named from Green River which now drains the lake bed) and an "island hill." The thickness of the lake deposit here is about 30 feet and the surface 381 to 385 feet above sea. The "island hill" is one of many peculiar partly-buried hills which rise sharply from the flat surface of the material deposited around them so that they bear a strong resemblance to islands rising above a water surface. The beach ridge shows well in the topography between Philips' store and the McLean County line.

streams; a deposit due to subsidence; a deposit due to climatic change; and in southwestern Wisconsin a closely related but predominantly stream-laid deposit has been attributed to glacial floods and deposits in the Mississippi Valley.

The clay is not glacial drift, for it contains no stones and little sand; and much of it lies outside the glacial boundary. Moreover, it is found only in the lowest places and its upper surface is horizontal without regard to the underlying surface of hard rock. It is not loess, for it fills all depressions up to certain altitudes and is not found at higher positions. Its thickness and others of the characters already described show that it is not a normal flood-plain deposit. It could scarcely be a simple back-water deposit from glacial floods without the help of a valley train, because that would require that the rivers have a sustained depth of about two hundred feet for the thousands of years it must have taken the clay to accumulate. A subsidence of the surface might lead to the development of a few bodies of clay having the shape and arrangement of those under discussion, but warping so complex as to cause the regular arrangement and shape of so many bodies of clay would be inconceivable. Nor could the deposits have been produced by climatic change, for such deposits slope down stream and these are horizontal. Finally, the limited up-stream extent of the clay, the fineness of the material, the horizontality of the surface, and the fact that the clay abuts against thick bodies of coarser material on the large rivers, indicate that most of the clay accumulated in lakes produced by valley fillings, the master drainage lines of the region. In order to understand the cause and history of the lakes it is therefore necessary to look into the history of the large rivers.

Valley filling on the Mississippi and Ohio.—The deposits on the Mississippi and Ohio consist principally of sand, but there is considerable gravel and silt, the gravel being more abundant at the base and the silt at the top. Most of the material lies below extreme high-water stage, and hence the surface forms a flood-plain, but here and there bodies of sand and gravel stand about 30 feet above the reach of high water, the upper surface in such places forming a terrace at the altitude of the valley filling on near-by tributaries.

Apparently the river valleys were once filled to a position as high as the surface of the filling on the tributaries, but have now been partly cleared out, the surface of the fill being lowered about 30 feet. The part remaining is about 150 feet thick and extends about 120 feet below low water, the range between high- and low-water stages being about 30 feet (see Fig. 3).

In this connection it seems worth while to note that when the discharge of a stream is increased, the vertical distance between the bottom of the channel and the flood-plain is also increased, and this comes about not alone by scouring out the channel, but also by building up the alluvium. Thus, without any change in size of load, it is possible to produce thick alluvium by simply increasing the volume of water.

To return to the lakes themselves: they differed from most bodies of quiet water in that the position of the surface varied greatly every year, for it was controlled by the various stages of the rivers. If the range between high and low water had been the same that it is now the surfaces of the lakes would have fluctuated between limits about 10 to 40 feet apart. But the lakes formed a huge reservoir so that with the same discharge as at present the rivers would not have risen nearly so much in times of flood.

Indeed, to raise the surface of the lakes and rivers one foot, it took over one hundred billion cubic feet or nearly a cubic mile of water; moreover, every rise of 5 or 10 feet would double the discharge of the rivers, so that tremendous floods could be taken care of without great increase in depth of water.

Terminology.—It seems probable that the rather extensive development of deposits and resulting topographic features such as are described in this paper will lead to the introduction of some new descriptive terms. Perhaps it will be found convenient to use "contragradation" or "dam gradation" for that kind of stream aggradation which is caused by an obstruction, or, more broadly, decrease in velocity, and perhaps to invent still other terms for the aggradation due to increase in load and decrease in volume. In case the obstruction develops so rapidly as to produce ponded water, such as is described in the present paper, the deposit is on the whole very fine-grained and the top nearly horizontal though

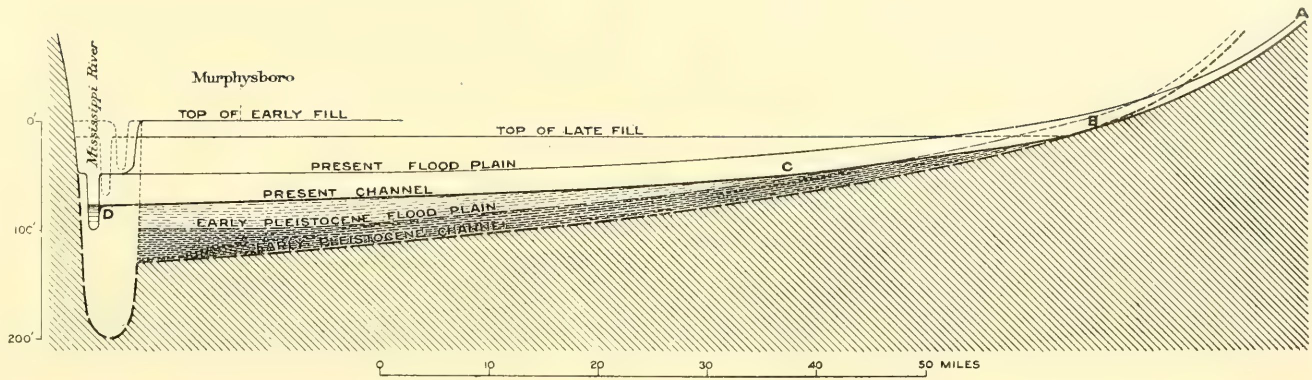

Fig. 3.—Longitudinal section of Muddy River deposits and cross-section of Mississippi River deposits. The filling material in Muddy River Valley, like that in many others, is for the most part very fine-grained silt and clay, in part fluvial and in part lacustrine. There seem to be two different fillings, and the top of each is horizontal. The lower part of the present flood-plain is horizontal and high above the present channel bottom, the distance being controlled by the range between high and low water on the Mississippi as far as back water from that stream reaches. The present profile reflects the history of the stream, the fall from A to B being moderate, B to C low, and C to D extremely low. The bed-rock profile of Muddy Valley is not adjusted to that of the Mississippi Valley, indicating a rapid deepening (Pleistocene?) of the Mississippi Valley. In order to show the profiles correctly the section was made on the whole course of Muddy River and not in a direct line from the source to the mouth.

more or less concave. For the resulting topographic feature, the bottom of Muddy River Valley may be taken as a type and *Muddy* may be an acceptable name for it, referring, as the name does, both to a particular type and to a principal character of the deposit, and the streams which flow over it, and also to the general character of the country where the feature is developed. On the other hand, in case aggradation keeps pace with the growth of the dam the material is in general coarser and the upper surface rises up stream, though at a less rate than the original stream channel. For this topographic feature the surface of the deposit forming a low terrace along Big Sandy River in eastern Kentucky may be taken as a type and called a *Sandy*. Perhaps also it will be found desirable to speak of the island-like hills surrounded by the deposit as *Island Hills*, and the hill bearing the town of Island, in Kentucky, may be taken as a type.

Summarizing.—The inferred history of the lake deposit reads about as follows: In middle or late glacial time the rivers were flowing on beds about 100 feet below their present ones. Whether this great depth was attained in an interglacial epoch by a regional uplift or was reached through the deep scouring of glacial floods has not yet been determined. The tributaries entered the flood-plains of the Mississippi and Ohio on channel bottoms only about 40 feet lower than those in use today and their flood-plains were near the position of their present channel bottoms, these positions being controlled by low- and high-water stages on the master streams. As at present, at low-water stage there was no standing water in the tributaries, but at high water the deep channels were filled by back water from the rivers, thus forming long, narrow winding lakes. When aggradation began on the Mississippi and Ohio, both low- and high-water marks on them and on the tributaries rose. At low water there were embryo, perennial lakes in the channels of the tributaries at their mouths and at high water the flood-plains were covered more deeply than before. The area covered both at low- and high-water stages gradually extended until low-water stage reached the altitude of the former flood-plain. From this time on there were perennial bodies of quiet water of considerable size on each tributary, and wedge-shaped masses of

lake deposit about 80 feet thick at the lower ends and thinning out to a feather edge up stream, accumulated on the old flood-plains.

Nearly all the material deposited in the lakes was fine sediment such as would be carried in suspension, and the lakes seem to have been filled with this material up to certain concordant positions, probably to the natural position of a flood-plain or just below the high-water mark of the time.

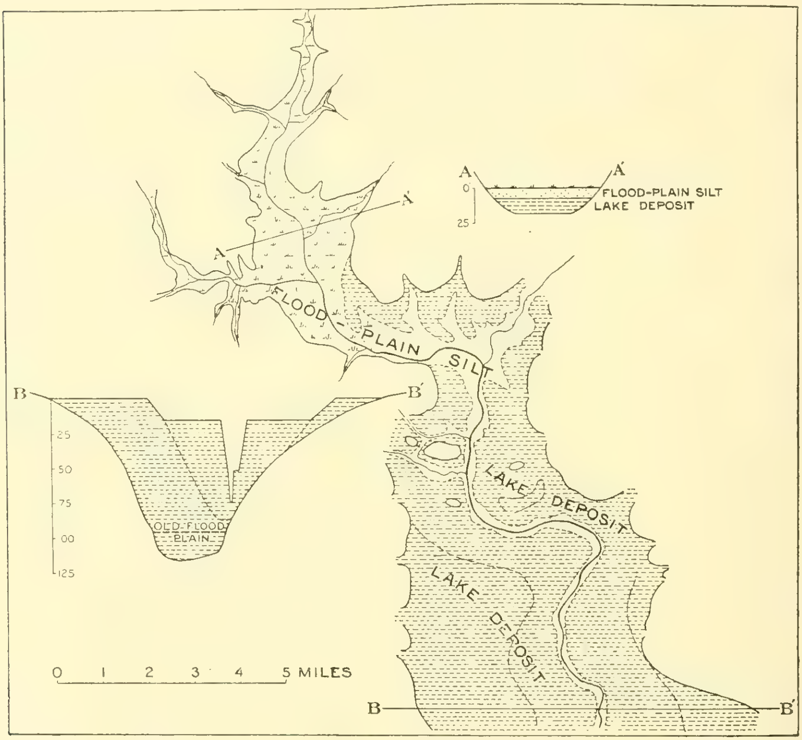

FIG. 4.—Diagram showing arrangement of principal deposits and surface features along Beaucoup Creek, Perry and Jackson counties, Illinois. The filling thickens and the flood-plain becomes narrower down stream. When the lake became extinct the bed became a great swamp. The stream first cut into the lower end of the fill, draining that part of the swamp and developing a narrow flood-plain below the surface of the lake silt. With further downward cutting the new flood-plain was lowered and extended up stream and the swamp area reduced. Meanwhile, stream deposits continued to accumulate at the upper end of the lake bed. Many other valley bottoms are similar, having a peculiar swampy central portion.

When the Mississippi and Ohio finally became not only able to carry all the load delivered to them but a little more, they began to cut down again. Perhaps even before this time the lakes had become intermittent, being drained except at times of high water, for they were almost filled with sediment. The great flat lake bottoms became swamps, and channels began to deepen again at the former outlets. At the same time the swamps themselves began to be drained at the lower ends. The process of swamp draining has continued to the present time, and on medium-sized streams there now remain only 10–20 miles of swamp, the lower 20–50 miles having been drained (see Fig 4).

GRAVEL AS A RESISTANT ROCK[1]

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INTRODUCTION

The thesis which this paper will endeavor to establish may be stated as follows: *Gravel, in its relation to the agencies of denudation, is, under certain geological conditions, a highly resistant rock. To these agencies it will, in general, offer greater resistance than ordinary igneous or sedimentary rocks, with a few possible exceptions.* On the validity of this thesis hinge important deductions as to the normal course of topographic development in cases where such gravel plays a prominent part in the geological structure of a region.

It is my purpose (1) to point out the theoretical reasons for the resistant nature of gravel deposits; (2) to show from an actual occurrence in nature that the gravels do behave as the theoretical considerations would lead us to expect; and (3) to sketch, by way of suggestion, the normal course of development of topography in a region where alluvial fans of coarse material are accumulating at the base of mountains. By way of suggestion there will be further a brief application of the principles brought out to certain well-known topographic features.

Except for the descriptive portion of the paper, which will be clearly distinguished, the article is an analytical study made mainly for the purpose of determining the influence of certain types of rocks upon the processes and rate of denudation, and of calling attention to what appears to be a normal cycle of denudation and the topographic development of mountains in an arid region, and to a lesser extent in a humid region as well.

At the present time no attempt will be made to review exhaustively the literature of the subject.

[1] Published by permission of the Director of the U.S. Geological Survey.

RESISTANT QUALITIES OF GRAVEL

It is natural to look upon gravels as weak rocks which may easily be removed by the agencies of denudation. While this is doubtless true for sand or possibly even for fine gravel, it is a view which does not hold true of gravel of a coarser nature such as accumulates at the base of mountain ranges either in arid or humid climates, or of river gravels of the coarser type such as the Lafayette gravels of the Mississippi Valley.

There are two essential reasons for the resistant quality of gravel as regards denudation. These are: (1) the selected nature of the material; (2) its porosity. As regards the first of these, gravel is a composite rock made up of units, each of which is selected on the basis of its ability to withstand the action of the agencies of destruction to which all rocks are subjected. These agencies of disintegration are both mechanical and chemical. With respect to the mechanical, gravel may be looked upon as a residue which has survived the rolling, pounding, and abrasion incident to its transportation along the stream course, an experience which, if the journey be a long one, effectively grinds down and destroys all but the most resistant of the materials subjected to it.

From the standpoint, also, of rock *decomposition* gravel is particularly resistant, for it is a rock whose component materials are severally selected on the basis of their ability to withstand such decomposition. In a region of normal development where there has been no interference with normal conditions by such accidents as glaciation, the stream gravels represent, in the main, only rocks or fragments of rocks which, by virtue of their resistant qualities, have been able to survive unchanged the decomposition and mechanical disintegration which has effectively destroyed the rock surrounding them. They have undergone successfully the ordeal which has destroyed the neighboring rock. They are therefore still able to resist further subjection to the action of the same agencies of change.

Physically also, gravel is especially fitted to resist disintegration because in it the component fragments are reduced to compact units unbroken, as a rule, by fractures or other lines of weakness. The surfaces are generally smoothed and give little opportunity for

the attack of frost or for the entrance of percolating water, while the comparatively small size of the units diminishes the activity of insolation as a disintegrating agent. For these reasons, while a massive quartzite, for instance, may be as resistant as gravel to disintegration due to either mechanical abrasion or chemical decomposition, it will be more likely, especially if in larger masses, to suffer more from the effects of insolation and frost.

From the foregoing it is clear that stream gravels, particularly the coarser ones, may properly be looked upon as *concentrates* of the most resistant elements of the rocks from which they are derived. It follows that a gravel of such a nature will be more resistant to the agencies of disintegration than the original rocks. From its very nature and origin a gravel deposit should be expected to offer great resistance to the normal agencies of sub-aerial denudation. This resistant quality is particularly significant in the development of the topography of gravel deposits, since, disintegration being at a minimum, bodily removal of the component units of the gravel is necessary for their reduction; and, as we shall point out later, bodily removal, too, is at a minimum except along the immediate courses of good-sized streams. In the latter situations this may be readily accomplished, but away from the actual stream course the removal of the material must necessarily be very slow. The importance of this point in relation to the dissection of the alluvial fans along the base of a mountain range will be more fully elaborated on a subsequent page.

The second characteristic of gravels which makes them resistant to the disintegrating and erosive forces which would wear them down is their porosity and the consequent comparatively slight development of surface drainage on the gravel areas. A gravel deposit of moderate coarseness offers the maximum of favorable conditions for the absorption and storage of the rain which falls upon its surface. This hinders the formation of small surface streams, and since, as we have seen, disintegration is at a minimum, and the removal of the gravel is almost entirely dependent upon the transporting action of such streams, the gravels are doubly protected from removal.

From the foregoing theoretical considerations we should expect

that gravel would be one of the most resistant of rocks as far as its relation to the processes of disintegration and removal is concerned.

Compare, for instance, the relative ease with which weathering and erosion break up and remove the rocks from an area of granite and from one of moderately coarse gravels in a similar situation. In the case of the granite there is always a greater or less number of joints or fissures through which water may enter and perform its work of disintegration either by direct chemical decomposition or by the subsidiary agency of frost. In contrast to this there are the smooth, usually fissureless surfaces of the gravel units. The granite is made up of a variety of minerals, some of which are easily attacked by the weathering agents. Some, it is true, are as resistant as the most resistant components of the gravel but in every case these are small, being limited in size by the texture of the granite. There is too, in a rock of complex mineral composition, the factor of pulling apart of the mineral grains by differential expansion and contraction.

The less resistant minerals, by weathering away and breaking down, leave the harder and more resistant ones free to be removed by the surface waters. Since, in general, the size of the grains is comparatively small, in a granite scarcely exceeding one centimeter in diameter, the resistant materials are readily removed by the streams in the form of sand, while the products of the more thorough disintegration of the less resistant minerals are easily carried away in suspension or solution or may even be, in considerable measure, picked up and carried off by the winds.

Thus we see that a granite is much more vulnerable to the attacks of the weathering agencies than a coarse gravel. What is true of granite is also true in varying measure of any of the less resistant sedimentary or igneous rocks, such as shale, soft sandstone or limestone, diorite, etc. In the case of quartzite and certain of the lavas it is a question which would disintegrate more rapidly, these or the gravel. The latter has in its favor, as a resistant rock, the factor of porosity and the slight effect of insolation.

All the above considerations apply particularly when the slope is low. On very steep slopes the lack of coherence of the gravel,

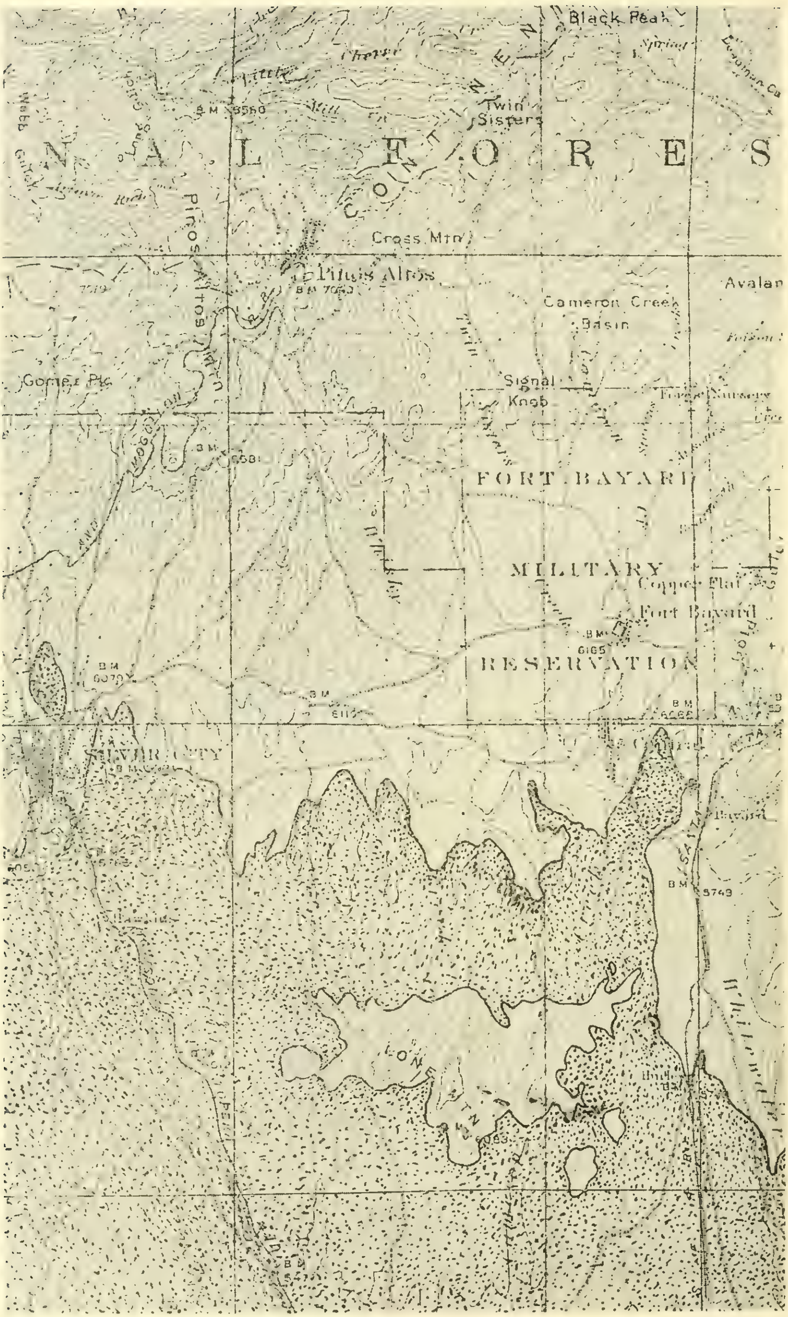

FIG. 1.—A portion of the Silver City quadrangle, N.M., showing the features described in the text. The gravel area is shown by the dotted pattern.

combined with the effect of gravity and the rapid mechanical erosion, would doubtless cause more rapid removal of gravel than of granite on account of the dominance of the factor of bodily transportation.

PIEDMONT GRAVELS NEAR SILVER CITY, NEW MEXICO

Near the town of Silver City, N.M., best shown between there and the smaller town of Central, seven miles directly to the east (see *U.S.G.S.*, Silver City quadrangle), there lies a gravel deposit of Piedmont nature which presents points of particular interest in connection with the thesis just presented. The road from Silver City to Central follows closely along the inner or mountainward margin of this deposit (Fig. 1) which extends from here southward for 40 or 50 miles as a part of the gravel fan of a great interior basin which, with its tributary basins, covers a large area in the southwestern part of the state.

The gravel plateau, as it will be called, in the portion under consideration between Silver City and Central, has a slope to the south of about 100 ft. per mile and strikes approximately east and west. It is characterized by great uniformity and evenness as seen from any point on the plateau surface. One sees merely a monotonous plain of gravel, horizontal as one looks to the east or west, but sloping always toward the south. This appearance of great evenness applies, however, only to the remnants as seen from a point on the plateau surface, for, particularly near the northern or mountainward margin, it is considerably dissected by streams which, flowing outward from their sources in the mountains, have carved long, usually nearly straight and parallel valleys down the dip of the plateau (Fig. 2). These valleys are cut to a depth of about 150 ft. at the maximum. As one follows them out toward the desert plain they gradually become shallower and finally disappear altogether. Degradation there gives place to aggradation.

The gravel of the plateau is composed of rocks found in place in the mountains and the whole character and relationship of the deposit points clearly to its origin as a Piedmont accumulation of gravel spread out from the adjacent mountains to the north at some earlier time before dissection set in.

While from its nature as a Piedmont accumulation, the gravel of the plateau has not suffered complete elimination of the less resistant elements, it is, nevertheless, an assorted mass in which rocks of the more resistant kinds strongly predominate. A list of a few of the more common of these will give a fair idea of the nature of the gravel and of the extent to which the more resistant rocks dominate. The list follows: green quartzite, white quartzite, light-colored rhyolite, basalt, diorite, epidotized granodiorite, garnet rock, and magnetite from the Hanover ore deposits.

FIG. 2.—Looking down one of the valleys which crosses the gravel plateau from the lowland to the desert beyond. Note particularly the character of the valley; its narrowness and lack of tributaries. Compare this with the broad valleys developed on the bed-rock of the lowland as shown in Fig. 3. Lone Mountain in the background.

The coarseness of the material varies. Individual bowlders of large size are buried in a matrix of smaller bowlders, pebbles, and sand. This combination gives a rock of very porous nature, capable of absorbing quickly the water which falls upon it. At the same time the removal of the finer material of the matrix leaves the coarser bowlders and pebbles concentrated at the surface where they form a very effective protective covering—effective against either rain erosion, wind, or decomposition.

The most conspicuous feature in connection with this plateau is the fact that it is now separated by a lowland from the moun-

tains which supplied the material for its construction. Nor is this lowland the site of a stream valley. It runs, on the contrary, parallel to the strike of the beds and is crossed directly by the course of all the streams which flow from the mountains out through the dissected plateau to the desert beyond.

A good idea of the nature of the lowland may be gained from the photograph, Fig. 3 (see also the map, Fig. 1). This shows the lowland in the foreground and to the left; the even-topped gravel plateau on the skyline; and, sloping down toward the observer,

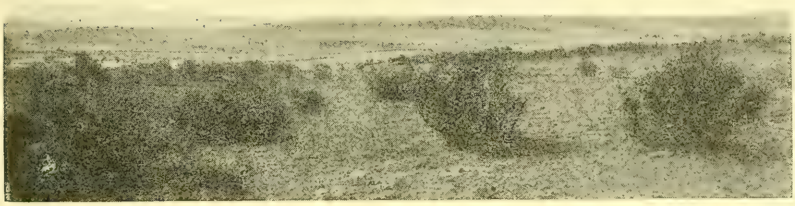

Fig. 3.—Looking southeast from the Central road three miles east of Silver City. This view shows clearly the even-topped gravel plateau and its inward slope toward the lowland in the foreground.

the inner scarp of the plateau facing the lowland at the divides between streams. The view is looking southeast from the Central road three miles east of Silver City.

On the interstream ridges the difference in elevation between the inner lowland and the tops of the plateau surface varies between 50 and 100 ft. In going northward along the tops of the divides, toward the mountains, one must travel from $\frac{1}{2}$ to 2 miles before he again encounters ground as high as the tops of the gravel plateau. If the dip slope of the plateau surface is projected across the lowland toward the mountains the present land surface is not intersected within a distance of about 4 miles, on the average, from the

general line of the gravel plateau. Such a projection may be assumed to be a minimum original slope, for it makes no allowance for an increased slope of the plateau surface nearer the mountains, as must have been the case if the gravels once covered the lowland. This feature is illustrated in the two profiles shown in Fig. 4, drawn to scale from two different points well out on the plateau northward across the lowland to the base of the mountains.

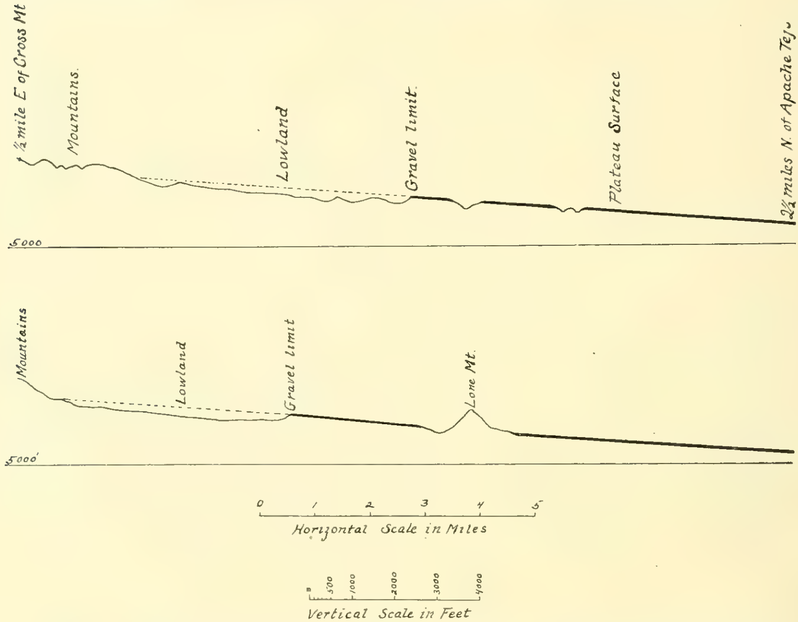

FIG. 4.—Profiles across the gravel plateau and the lowland from points on the desert to the foot of the mountains, showing the projected gravel surface and the relations of the gravels to the mountains.

With topographic relations as they are at present the nearest possible source of the gravels of the plateau is separated from it by a lowland averaging 4 miles in width. It will be at once evident that, at the time of the formation of the plateau, the lowland could not have existed in its present relation. Any one of three things may have happened to bring about present conditions: (1) The gravels may have been removed by erosion from the area between their present limit and the mountains; (2) there may have been faulting by which the lowland was relatively lowered; or (3) the mountains

may have worn back and the lowland developed by differential erosion since the deposition of the gravels.

Opposed to the first of these alternatives is the fact that the gravel plateau ends abruptly along a relatively straight line. There are no outliers of gravel between this general line and the mountains. It is highly improbable that streams flowing nearly parallel and not more than a mile apart should strip all signs of the gravels from the upper four miles of their course, while in their lower course, where they flow across the gravel plateau, they should be in relatively narrow valleys with almost no tributaries and should have done little more than to cut their way through the plateau without having been able to widen their valleys to any great extent (Fig. 2).

A second objection is the fact that the line of contact between the gravels and the underyling rock slopes upward toward the moun-

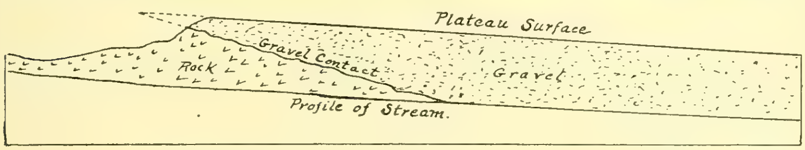

Fig. 5.—Sketch showing the relation between the gravels of the plateau and the underlying rock which indicates that the gravels never reached much nearer the mountains than now.

tains at such an angle that it would intersect the projected line of the plateau surface at a point not far within the present limit of the gravels (see Fig. 5). In other words the gravels thin toward the mountains at such a rate that they would wedge out within a short distance from their present limit, and the lowland is accordingly developed in the bed-rock.

A third objection is raised by the fact that in the gravels of the plateau there are aggregations or nests of huge lava bowlders, some of them 15 feet in diameter, which indicates that the mountians must at one time have been closer, for bowlders of such size are too large to be carried far by water, particularly by water flowing on a slope of 100 ft. per mile, which is approximately that of the plateau surface.

The second alternative, faulting, seems highly improbable, for there is no evidence whatever of the presence of faults along the

line between the gravels and the lowland. At Silver City a tongue of the gravel plateau extends with accordant grade directly across the line of any fault which might have uplifted the gravels farther east. Further conclusive evidence of the lack of fault relationships of the lowland is furnished by the fact that the contact between the gravels and the underlying rock runs down the valleys and up across the interstream ridges in a perfectly normal manner, and with such wide divergence from a straight line as to preclude the possibility of an explanation by faulting.

The failure of the first two hypotheses to account for the inner lowland leaves only the third, that of differential erosion. This calls for, first, the formation of the plateau as a Piedmont plain of accumulation at the base of the mountains; later, the cessation of active aggradation, possibly because of a lowering of the mountains through erosion; the initiation of a degradational phase of activity; and finally, the gradual erosional retreat of the mountain front and the reduction of the intermediate land at a rate faster than that of the gravels, leaving them standing in their present relations.

Important in this connection is the nature of the rock composing the lowland. It is, in the main, a series of soft Cretaceous shales cut by dikes of a moderately resistant igneous rock. In parts of the lowland the shales are absent and the bed-rock is igneous. This, however, makes little difference in the nature of the resulting topography. Everything is worn down to a nearly uniform level lower than that of the gravels.

A discussion of all the possible causes of the change in the phase of activity from one of aggradation to one of degradation would be out of place here. Two such may, however, be mentioned. The first is change in climate, the second, a lowering of the mountains by erosion with consequent relative increase in the factor of decomposition, over that of disintegration and transportation, brought about by the lessened slope.

If the same process of differential erosion continues, the mountains will eventually become much reduced in height while the gravels, suffering less by erosion, will stand relatively higher and may finally come to dominate the topography of the surrounding

country. With respect to the drainage to the south, the extent to which this process can be carried is limited by the base level of the interior basin to which the streams are tributary.

A factor which must profoundly affect the topographic development of the whole region is the Gila River with its tributaries which, passing within 20 miles of Silver City, to the northwest, drains a large proportion of the mountain area. The Gila drains directly to the sea, and being a good-sized permanent stream, whose valley is some 1,600 ft. lower than the gravel plateau, it is actively pushing its headwaters southeastward into the drainage area of the interior basin in which the plateau is situated. The divide, in one place, now lies only 6 miles from the gravel plateau and is only 400 ft. higher. The Gila affords opportunity for the free removal of the waste from the mountains. Short and steep slopes combine to increase its effectiveness.

Eventually the normal outcome of processes now in operation should be that the mountains would become lowered; the interior lowland between the plateau and the mountains would, by capture, become tributary to the Gila; and the plateau itself, remaining higher on account of its superior resistance to erosion, would terminate in a scarp overlooking the lower lands to the north.

SIMILAR FEATURES IN OTHER REGIONS

Other areas are known where gravel deposits of a nature similar to those on the plateau east of Silver City occupy a similar topographic position and seem to show much the same history.

A good example, with which the writer is familiar, is the Bishop conglomerate of southwestern Wyoming and northeastern Utah. This represents a Piedmont gravel accumulation derived from the Uinta Mountains, and at one time skirting entirely round their base. Subsequent erosion has so lowered the mountains that over considerable areas, particularly at the eastern end, they are actually lower than the tops of the gravel-capped plateaus which represent the eroded remnants of the Piedmont gravel deposits. This condition has been described by the writer in an earlier paper.[1] Between

[1] "The Physiography of the Bishop Conglomerate, Southwestern Wyoming," *Jour. Geol.*, XVIII, No. 7 (1910), 601–32.

the mountains and the plateau are valleys sometimes 10 to 15 miles wide, and as much as 2,500 ft. deep (*ibid.*, p. 622). Other observers who have worked on the south side of the range report similar conditions there.

The resistant qualities of the gravel are particularly well illustrated by the Bishop conglomerate. The plateaus have remained with little change while general erosion has lowered the surrounding country nearly 1,000 ft. on the average.

In point of origin and later development, the Bishop conglomerate is thought to represent exactly the same type of phenomenon as we have described from the Silver City region; the only difference being that, in the former case, the process has been carried farther and the results are just so much the more striking.

CYCLE OF MOUNTAIN DEVELOPMENT

If the above analysis is correct, as it seems to be, both from the theoretical side and from field observation, the influence of gravel deposits is an important factor to be considered in the cycle of development of mountain topography. This cycle is admittedly complex, involving many factors, but for the purpose of clearly presenting the point especially in mind at the present time, it is not necessary to follow each of the factors involved. On the contrary, the consideration of the subject will be confined, as far as practicable, to a brief outline of the manner in which gravels, by reason of their selected nature, suffer less than other rocks.

At the initiation of the cycle of mountain development let us postulate the following ideal conditions: A mountain range, or simple fault block of moderately resistant and varied rocks sharply uplifted above the surrounding country. Free drainage from the foot of the mountains to some base level, either of interior or of exterior drainage, lying at a considerably lower elevation. In order to give the maximum of favorable conditions, we will postulate further that the climate is semi-arid so that vegetation plays a subordinate rôle.

Granting these initial conditions, and assuming that there are no further crustal movements, let us trace the development of the mountain range.

At first, with steep, exposed slopes, *disintegration*, through frost and insolation, and *erosion* will be rapid. The streams, while powerful enough to carry the loosened material down the steep slopes, will be unable to transport it across the lowland below. Piedmont fans of coarse gravel will accumulate along the mountain base. As time goes on the fans will continue to grow at the expense of the mountains. During this stage the fans are the seat of continual deposition, the mountains of continual waste and removal. Finally there must come a time when the mountains have become so lowered that the streams are no longer flowing over steep slopes. As this stage is approached, disintegration and decomposition within the mountain area will become relatively more important and the rocks will be reduced to a finer condition before being carried off. The streams will no longer be overburdened with sediment too coarse to be carried beyond the base of the mountain. At this point the upbuilding of the fans at the immediate mountain base must cease while the locus of deposition is shifted farther out because the stream load, being of a finer nature, may be carried to a greater distance before deposition occurs.

This is the turning-point in the history of the mountain range. From now on, both mountains and fans will be subject to denudation or degradation. If both the fans and the mountains were worn down at an equal rate, the whole area would merely lose in elevation without any marked change in the relations of mountains and gravels. Since, however, according to our thesis, the gravels will suffer from erosion less than the rocks of the mountains, differential erosion becomes an important factor. As the slopes decrease and decomposition plays an increasingly important rôle while the material furnished to the streams becomes finer and less in amount, the burden of the streams becomes less and they are able to cut where deposition was in progress before, and will sink their channels into the Piedmont fans.

Since the mountains are lowered faster than the gravels, a lowland will gradually develop, beginning first near the position of the inner margin of the gravel at the time of the change from aggradation to degradation. If the base level of the streams is sufficiently low, this lowland may eventually come to include the whole of the

mountain area. If the streams crossing the Piedmont gravel fans sink deeply enough they may finally cut entirely through the gravel into the underlying rock. In that case we will have a plateau between the streams, capped by gravels of a composition corresponding to that of the rocks of the lowland which occupies the site of the original mountains, but lying at a level higher than the summits of these mountains as they now exist.

Various combinations of factors will modify in different ways the course of development as sketched above, but the general principle involved should hold true, and the results should be in harmony with this principle as modified by the particular factors dominating in any one case.

EXAMPLES ILLUSTRATING THE TYPE OF DEVELOPMENT ABOVE OUTLINED

As examples of the influence of the slower differential erosion of gravel deposits the following may be mentioned: The region east of Silver City; the Uinta Mountains and the associated Bishop conglomerate, both described in the preceding pages. The Catskill Mountains of New York, in their relation to the old lowland to the east, are a possible illustration of the principle.

THE CRETACEOUS AND TERTIARY FORMATIONS OF WESTERN NORTH DAKOTA AND EASTERN MONTANA

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CONTENTS

INTRODUCTION

The Cretaceous formations represented in the area under discussion are the Pierre shale and Fox Hills sandstone. Overlying the latter is a non-marine formation, which has variously been called "the Ceratops beds," "Lower Fort Union," "Somber beds," "Laramie," "Hell Creek beds," and "Lance formation." The United States Geological Survey has recently adopted the name "Lance formation," derived from the term "Lance Creek beds," which was applied to the deposits by J. B. Hatcher, and this name is employed in the following pages. The age of the Lance formation is still unsettled, some geologists regarding it as part of the Fort Union and thus early Eocene in age, while others believe that it included, or is part of the Laramie and is, therefore, Cretaceous. The Tertiary formations are represented by the Fort Union and White River.

Western North Dakota is particularly favorable for the study of these formations, since they are excellently exposed in the Little Missouri badlands and along the valley of the Missouri and its tributaries. Bowman and Billings counties afford a continuous section extending from the Pierre shale up through the Fox Hills, Lance formation, and Fort Union to the White River beds of the Oligocene, involving a thickness of some 2,150 feet of strata.

The data here presented were gathered during seven seasons of field work in North Dakota and Montana, a portion of the time as assistant on the United States Geological Survey, and a portion

under the auspices of the North Dakota Geological Survey. The work in Montana was confined mostly to Dawson and Custer counties; the Yellowstone River having been followed from its mouth to Miles City, and a trip being taken north from Miles City to the Hell Creek region and across the Missouri River to Glasgow.

PIERRE SHALE

The Pierre shale is exposed along the Missouri River for a distance of about twenty miles north of the South Dakota line, or as far as the mouth of Big Beaver Creek in Emmons County; in eastern Montana it appears along the Missouri Valley from a point probably as far west as the Musselshell River to the station of Brockton, on the Great Northern railroad, or a distance of nearly 180 miles; it also occupies a small area on Little Beaver Creek in northwestern Bowman County, North Dakota, which is probably continuous with the Pierre outcrop on the Yellowstone River, twelve miles above Glendive.

The Pierre formation is a bluish gray to dark gray, sometimes almost black, jointed shale, which often weathers into small, flaky fragments. The rock commonly shows yellow spots or stains of iron oxide. The topmost beds of the Pierre contain numerous calcareous concretions varying in size from a few inches to six and eight feet in diameter. Some of these concretions are rich in invertebrates, which are characteristic of the upper forty or fifty feet of the Pierre, while others are barren of fossils. Many are cut by a network of calcite veins which are commonly lighter colored than the matrix. The following species, identified by Dr. T. W. Stanton, were collected in the Little Beaver Creek locality, Bowman County, North Dakota:

Ostrea pellucida M. and H.
Avicula linguæformis E. and S.
Inoceramus cripsi var. barabini Morton.
Chlamys nebrascensis M. and H.
Yoldia evansi M. and H.
Nucula cancellata M. and H.
Lucina occidentalis Morton.
Protocardia subquadrata E. and S.
Callista deweyi M. and H.
Lunatia.
Anisomyon patelliformis M. and H.
Margarita nebrascensis M. and H.
Fasciolaria? (Cryptorhytis) flexicostata M. and H.
Pyrifusus.
Haminea? occidentalis M. and H.
Scaphites nodosus Owen vars. brevis and plenus.
Nautilus dekayi Morton.

From the locality on the Yellowstone, at the mouth of Cedar Creek, the following marine shells were secured, from the upper fifty feet of the Pierre:

Avicula nebrascana M. and H.
Avicula linguaeformis E. and S.
Inoceramus sagensis Owen.
Inoceramus cripsi var. barabini Morton.
Modiola meeki E. and S.
Veniella subtumida M. and H.
Callista deweyi M. and H.
Anchura americana E. and S.
Haminea occidentalis M. and H.
Pyrifusus newberryi M. and H.
Lunatia concinna M. and H.
Scaphites nodosus var. quadrangularis M. and H.
Scaphites nodosus Owen vars. brevis and plenus.
Limopsis parvula M. and H.
Yoldia evansi M. and H.
Lucina subundata M. and H.
Protocardia subquadrata E. and S.
Dentalium gracile M. and H.
Vanikoro ambigua M. and H.
Margarita nebrascensis M. and H.
Fasciolaria (Piestocheilus) culbertsoni M. and H.
Baculites ovatus Say.
Nautilus dekayi Morton.
Chlamys nebrascensis M. and H.

The beds which outcrop at the latter locality on the Yellowstone, twelve miles above Glendive, Montana, are brought above river level by an anticlinal fold, the dip of the strata here being 20° S. 52° W. The Bowman County outcrop is probably caused by the same anticline, since the strike of S. 38° E. shows that the fold so well exposed on the Yellowstone, if continued in that direction, would include the Little Beaver Creek locality. That the two areas of outcrop are continuous seems probable from the fact that ammonites and other marine shells are reported to have been found at several intervening points on Cabin and Cedar creeks.

There are extensive outcrops of Pierre shale along the Missouri River and its tributaries in the northeastern corner of Montana, in Dawson and Valley counties. At the mouth of Big Dry Creek, fifteen miles south of Glasgow, the shale rises 200 feet above the river, and it is also well shown on most of the creeks entering the Missouri from the south for a distance of eighty or one hundred miles west of the Big Dry. Among these is Hell Creek, on which 150 feet of Pierre are exposed above creek level. Among the most common fossils occurring in the calcareous concretions of this locality are ammonites and baculites.

In the southeastern corner of Custer County, Montana, as a result of the Black Hills uplift, the Pierre shale outcrops over an area of considerable extent, overlying the Benton and Niobrara formations, which also appear at the surface.

FOX HILLS SANDSTONE

The Fox Hills sandstone is the most recent of the marine formations of the Great Plains region. It is very variable in character and undergoes considerable change in composition and appearance from one locality to another. It is exposed on the Missouri River as far north as old Fort Rice, about eight miles above the mouth of the Cannon Ball River; it appears on Little Beaver Creek, a tributary of the Little Missouri in southwestern North Dakota; on the Yellowstone a few miles above Glendive, Montana; it occurs in the Hell Creek region, and also on the Missouri River, near the town of Brockton, Montana.

On the lower Cannon Ball River, for a distance of ten or twelve miles above its mouth, the Fox Hills formation is exceptionally well shown. In many places it forms cliffs rising abruptly from the water's edge, and the cuts made for the new branch line of the Northern Pacific afford many excellent exposures. It rises eighty to ninety feet above the Cannon Ball River, or approximately 1,680 feet above sea-level.

The Fox Hills sandstone when unweathered is gray with yellow patches, but in weathered outcrops it is yellow or brown in color. The rock is rather fine-grained and, for the most part, so soft and friable that it can be crumbled in the hand. Cross-bedding is very common and the rock contains great numbers of large and small ferruginous sandstone concretions or nodules, many of these likewise exhibiting cross-bedding. The nodules are apparently due to the segregation of the iron into irregular patches cementing the sand into firm, hard masses, considerably harder than the sandstone in which they are imbedded. In many places the iron has impregnated certain layers and formed indurated ledges, which resist weathering and project beyond the softer portions (Fig. 1). The nodules vary in size from an inch and less to six and eight feet. Small, irregular, twisted or stem-like forms are

abundant at certain points. Some portions of the rock are so completely filled with these brown concretions that they constitute the main bulk of the formation, and the gray, loosely cemented sandstone forms a kind of matrix in which the hard nodules are imbedded. In the process of weathering these more resistant nodules project far beyond the softer rock, and at the base of slopes and scattered over the surface they are exceedingly abundant.

FIG. 1.—The Fox Hills sandstone on Cannon Ball River, North Dakota, showing hard ledges and concretions on a weathered surface.

Where the rock has only a few concretions, and therefore, where the iron has not been segregated to as large an extent at certain points, the sandstone is of a yellow color, due to the disseminated iron oxide. On the other hand, where the brown ferruginous nodules are thickly scattered through the beds, the rest of the rock is gray, the iron having been largely leached from it and concentrated in the nodules. Many of the latter are of good size and spherical in shape, and it is these which have given its name to the

Cannon Ball River, since they occur abundantly along that stream.

The following Fox Hills fossils were collected on the Cannon Ball River about ten miles above its mouth:[1]

Tancredia americana M. and H.
Callista deweyi M. and H.
Tellina scitula M. and H.
Ostrea pellucida M. and H.
Avicula linguiformis E. and S.
Avicula nebrascana E. and S.
Protocardia subquadrata E. and S.
Mactra warrenana M. and H.
Mactra ? sp.
Scaphites cheyennensis (Owen).

The first three in the above list occurred in a bed of sandstone forty feet below the top of the formation, while the others were from a higher horizon, ten feet below the top of the Fox Hills.

About three miles below this locality specimens of *Mactra warrenana* M. and H., *Dentalium gracile* M. and H. ? and *Cinulia cincinna* (M. and H.) ? were collected.

On Long Lake Creek, a tributary of the Missouri River, from the east the sandstone yielded the following: *Avicula linguiformis* E. and S., *Tellina scitula* M. and H., and *Chemnitzia cerithiformis* M. and H. ?

The contact of the Fox Hills sandstone with the overlying Lance formation is well shown in the bluffs on the north side of the Cannon Ball River, about ten miles above its mouth. Here the two formations are seen to be conformable, the top of the Fox Hills being marked by a light gray, almost white sandstone, which exhibits cross-bedding (Fig. 2). This bed is one foot to eighteen inches thick. Sedimentation was apparently continuous from Fox Hills time on into the period when the Lance beds were being formed.

East of the Missouri River, in Emmons County, the sandstone is present on Beaver Creek, extending up the valley of that stream almost to Linton, and having an elevation of nearly 150 feet above the creek, near its mouth.

About 160 miles west of the Missouri River, the Fox Hills sandstone is exposed in a small area on Little Beaver Creek, in the northwest corner of Bowman County, North Dakota. The section here is as follows:

[1] Identified by Dr. T. W. Stanton.

	Feet
Sandstone, massive, light greenish gray, weathers to yellow color......	50
Sandstone ledge, yellow..	8–10
Clay, sandy, finely laminated and formed of alternating light and dark laminae. Contains nodules of iron pyrites. Exposed above creek level..	25

In this upper sandstone, Dr. T. W. Stanton collected several marine fossils characteristic of the Fox Hills, including *Leda*

Fig. 2.—The Fox Hills and Lance formations on the Cannon Ball River. The contact is at the hard ledge on which the man is standing.

(Yoldia) *evansi*, *Tellina scitula*, *Entalis? paupercula*, and *Halymenites major*.

Where exposed in bluffs along Little Beaver Creek, at several points the gray sandstone shows an uneven, eroded surface, which the writer has described as an unconformity.[1] It may, however, be due to the action of currents in the shallow sea of Fox Hills time, as suggested by Dr. Stanton, in which case no long

[1] *Fifth Biennial Report, N.D. Geol. Surv.*, 44.

time interval between the deposition of the sandstone and the overlying Lance beds would be indicated by the eroded surface of the Fox Hills.

In the vicinity of Iron Bluffs, on the Yellowstone twelve miles southwest of Glendive, Montana, the Pierre is overlain by 150 feet of sandstones and shales, the age of which is in doubt, though the beds have the stratigraphic position of the Fox Hills. The lower seventy-five feet is composed of shales and sandstones while the upper half is formed of a brownish sandstone. The only fossils found in these beds at this locality are some plants, which are too fragmentary to be identified.

The Fox Hills sandstone is well exposed on Hell Creek, a tributary of the Missouri River in northwestern Dawson County, Montana. Lying above the dark gray Pierre shale, with its fossiliferous concretions, are 100 feet of shales and sandstone belonging to the Fox Hills. The formation is here composed of light gray to yellow, more or less sandy shale, with some layers of nearly pure sandstone. About eight feet below the top, there is quite a persistent bed of fine-grained yellow sandstone with a thickness of eleven feet (Fig. 3). The beds are lighter in color and, for the most part, more sandy than the Pierre shale. From concretions near the summit of the Fox Hills on Hell Creek, Mr. Barnum Brown collected the following shells:[1]

Cardium (Protocardium) subquadratum E. and S.
Nucula cancellata M. and H.
Tellina scitula M. and H.
Yoldia evansi M. and H.
Crenella elegantula M. and H.
Piestochilus culbertsoni M. and H.
Anchura (Drepanochilus) americana E. and S.
Lunatia concinna M. and H.
Cylichna scitula ? H. and M.
Baculites ovatus Say.
Scaphites conradi Morton.
Chemnitzia cerithiformis M. and H.
Mactra ? nitidula M. and H.
Actaeon (Oligoptycha) concinnus M. and H.

Along the Missouri River valley, over 100 miles northeast of Hell Creek, and near the station of Brockton, on the Great Northern Railroad yellow sandstones interstratified with gray clay are found overlying the Pierre.[2] These beds are probably to be referred to

[1] *Bull. Am. Mus. Nat. Hist.*, XXIII, 827.

[2] Carl D. Smith, *Bull. U.S. Geol. Surv., No. 381*, 38.

the Fox Hills formation. Their thickness is about 200 feet and they are well exposed in the river bluff south of Brockton. As a rule the sandstone is soft, but in places there are hard concretion-like masses, which after weathering stand out as ledges or as cannon-ball shaped masses imbedded in a matrix of softer rock. The material shows much irregularity of bedding, is in places cross-bedded, and is extremely variable in character horizontally.

FIG. 3.—The Fox Hills formation on Hell Creek, Montana, showing sandstone ledge (A) near the top.

The Fox Hills sandstone probably occurs also about the Pierre shale area in southeastern Custer County, Montana.

The variability of the Fox Hills formation is well illustrated by the foregoing description of its outcrops. In some places, it is composed wholly of sandstone, in others it is mostly a sandy shale, while in still others it is partly sandstone and partly shale. When shales are present they are generally arenaceous and are commonly

most abundant toward the base of the formation, where, in some places, they pass gradually into the Pierre shale. It will be seen from the above lists that some of the fossils occurring in the upper part of the Pierre range up into the Fox Hills. The top of the latter is better defined than its base, the change from it to the overlying Lance beds in some places being abrupt, but generally the two are conformable. The Fox Hills beds vary in thickness from seventy-five to two hundred feet.

LANCE FORMATION

The Lance beds have a wide distribution in North Dakota and eastern Montana, as well as in northwestern South Dakota and northeastern Wyoming. The largest area in North Dakota is in the south-central part of the state, where this formation occupies a large part of Morton county and all of the Standing Rock Indian Reservation, outside the Fox Hills and Pierre outcrops; east of the Missouri River, it covers southern Burleigh and the greater part of Emmons County, together with adjoining portions of Kidder, Logan, and McIntosh counties. In the southwestern corner of North Dakota is a second smaller area stretching along the Little Missouri River for a distance of over fifty miles in western Bowman and southern Billings counties. In eastern Montana the Lance beds are found along the Yellowstone River from the vicinity of Forsyth to a point about fifteen miles below Glendive. South of the Yellowstone, these beds are exposed along the valleys of the Powder and Tongue rivers and their tributaries. The badlands occupying a wide strip of country on the south side of the Missouri River in northern Dawson County are for the most part formed of Lance beds, and they extend as far east as Brockton. According to C. D. Smith[1] the formation is found on the Fort Peck Indian Reservation, and the beds also occur west and north of the reservation in Valley County, Montana.

South-central North Dakota area.—In Morton County, North Dakota, numerous good outcrops of the Lance formation appear along the Missouri, Cannon Ball, and Heart rivers and many of the smaller streams (Fig. 4). The beds are found along the Mis-

[1] *Bull. U.S. Geol. Surv., No. 381,* 39.

souri River to within eight or ten miles of Washburn, where they disappear below river level and are replaced by the Fort Union. On the North Fork of the Cannon Ball they extend almost as far west as the Hettinger County line, and on the Heart River they reach to within a few miles of the Stark County line. Along the boundary between North and South Dakota the western border

FIG. 4.—Bluff of Missouri River near old Fort Rice, showing the lower Lance formation.

of the formation is not far from Haynes, on the Chicago, Milwaukee and Puget Sound Railroad.

In passing down the North Fork of the Cannon Ball River from the western edge of Morton County to the junction with the South Fork, and thence down the Cannon Ball River to its mouth, one traverses the entire thickness of the Lance formation from the Fort Union above to the Fox Hills below. About ten miles below the Hettinger County line, in sec. 5, T. 133 N., R. 89 W., the

contact of the Fort Union and Lance beds is well shown in the following section, exposed in a high bluff of the river:

	Feet	Inches
15. Shale, light gray and yellow, to top of bluff	16	
14. Shale, chocolate brown	1	6
13. Shale, light gray	6	
12. Shale, light yellow, soft, and readily crumbled	6	
11. Shale, light gray	15	
10. Coal	4	2
9. Shale, gray	23	
8. Coal	2	
7. Shale	1	6
6. Coal		31
5. Shale, sandy, light gray	10	
4. Coal	1	6
3. Sandstone, light gray, cross-bedded	25	
2. Shale, sandy, brown, with much iron		4–6
1. Sandstone, soft, yellow, with concretions and some thin limonitic streaks, exposed above river	50	
	163	9

Nos. 1, 2, and 3 of the above section belong to the Lance formation, while the other members are Fort Union. As is the case at a number of points, a coal bed (No. 4) occurs at the contact, and there are also two workable beds above this. The upper sandstone of the Lance formation extends down the river seven or eight miles below this section, forming in many places vertical cliffs rising from the water's edge. Then a dark shale appears beneath the sandstone as shown in the following section, which is seen about ten miles below the previous one, in secs. 29 and 30, T. 133 N., R. 88 W.:

	Feet
5. Sandstone, soft, yellow, to top of bluff	20
4. Shale, dark gray to black, alternating with thin-bedded, shaly sandstone	15
3. Shale, dark gray to black, when moist	70
2. Sandstone, yellow, with hard ledge near top	20
1. Shale, dark gray to black, sandy, exposed above river	25
	150

Only twenty feet of the upper sandstone of the Lance formation appear at this point, and the bluffs are here formed largely of the underlying black shale.

The beds near the middle portion of the Lance formation are well exposed in the bluffs on the south side of the Cannon Ball River near Shields where the following section occurs:

	Feet	Inches
Soil and subsoil	4–5	
Sandstone, yellow to gray, soft and friable	31	
Shale, gray and yellow	10	
Sandstone, gray and yellow, containing thin shale layers and brown, carbonaceous streaks	38	
Shale, gray, containing iron concretions	15	6
Shale, black and brown, carbonaceous; containing dark brown ferruginous concretions		6–10
Shale, gray	15	6
Shale, brown, carbonaceous	1	
Shale, gray, sandy	3	
Shale, brown, carbonaceous		18
Coal		6
Shale, black, coaly	1	4
Shale, gray, sandy	11	
Shale, brown, carbonaceous	1	6
Shale, very sandy	1	6
Shale, brown, carbonaceous	2	6
Shale, gray	7	6
Sandstone, gray, soft, with shale layer near middle, 2–4 feet thick	44	
Shale, gray	8	
Unexposed to river	20	
Total	219	

One of the characteristics of the Lance beds, exhibited in many widely scattered localities, is well shown in this section; namely, the many brown, carbonaceous layers which are present, often forming a conspicuous feature of the formation, as along the Little Missouri River. It will be noted that the beds are here composed about evenly of shales and sandstones, though the latter are confined to three thick members.

About thirty miles below Shields, and ten or twelve miles above the mouth of the Cannon Ball, the lower Lance beds are exposed, together with the underlying Fox Hills sandstone, as shown in the following section:

	Feet
Drift gravel and sand	2
Shale, dark colored	27
Sandstone, soft, with many thin, brown, carbonaceous laminae	11
Sandstone, yellow, soft	16
Shale, brown, carbonaceous, with two coal seams, one 3 inches and the other 7 inches thick	8
Shale, gray	3
Sandstone, gray	8
Shale, gray	4
Shale, brown, carbonaceous	3
Sandstone and shale in alternating layers, the former predominating; colors, dark gray, brown, and yellow	57
Shale, dark gray, with a few brown bands	22
Sandstone, Fox Hills	80
Total	241

From the lower sandstone of this section, Fox Hills shells were collected. The Lance beds here rest conformably on this sandstone, and there appears to have been a gradual change from the marine conditions of Fox Hills time to the fresh-water conditions under which the Lance beds accumulated, with continuous deposition throughout.

The strata forming the upper 350 feet of the Lance formation, comprising the upper, massive sandstone, and the underlying dark shales, are very well exposed in the valley of the Heart River, in Morton County. For a distance of five or six miles below the bridge on the Glen Ullin–Leipzig road, this valley is a narrow gorge walled in by sandstone cliffs. This rock, which forms the upper member of the Lance formation, is a massive, gray, brown, and yellow sandstone, having a thickness of approximately one hundred feet. The underlying shales are dark gray to black, when moist, and weather to a yellow color. They are cut by several sets of joint cracks and along these cracks the change from gray to yellow first takes place, the gray, unweathered material being left in the areas inclosed by the joints. Near the surface the shales are weathered and oxidized throughout, but at some depth the yellow color is confined to narrow bands on either side

of the joint cracks. In places, these beds are composed of thin layers of black shale and gray, very sandy shale, or sand.

On the Heart River, south of Almont, the following section appears, embracing portions of both the Lance and Fort Union formations:

	Feet
5. Sandstone, yellow, soft, massive	50
4. Shale, yellow and light gray	61
3. Sandstone, white	30
2. Sandstone, yellow and brown below, gray toward top. The upper sandstone of the Lance formation	95
1. Shales, dark colored	180
	416

Nos. 1 and 2 belong to the Lance formation, while the three upper numbers are Fort Union. On the Heart River in the vicinity of Mandan and in the bluffs of the Missouri near Bismarck, the Lance beds are made up chiefly of the dark shales, as is evident from the two sections which follow. The first is exposed at the east end of the Northern Pacific railroad bridge over the Missouri River.

	Feet	Inches
Drift, resting on the eroded surface of the Lance formation	15–20	
Shale, dark gray to black, with thin, light gray streaks; cut by many joint cracks several inches apart. Faces of the joints stained by iron	42	
Shale, sandy, black	1	
Shale, black	3	6
Sandstone, dark gray to black	1	
Shale, black	2	6
Sandstone, yellow	4	
Shale, dark gray to black, alternating with yellow, fine-grained sandstone and sandy shale	22	
Shale, black	30	
Unexposed to river level	15	
Total	141	

The second section appears on the south side of the Heart River two miles above Mandan, and is as follows:

	Feet	Inches
Soil, sandy	3	
Sand, Pleistocene	20	
Shale, gray and black, mottled; arenaceous in part, the sand being very fine; sandy layers have yellow color. Some portions contain considerable carbonaceous material, which gives the rock its black color. Shale cut by several sets of joints running irregularly in many directions, but all making large angle with the horizontal. These joint cracks are filled with gypsum and the sides stained with iron. The mottled character shows on weathered face of the bluff, where there are large blotches of black on the gray surface	28	
Shale, dark gray and yellow, some layers sandy; more thinly bedded than overlying member	7	6
Sandstone, soft, fine-grained, gray, and yellow	7	6
Sandstone, argillaceous, forming hard projecting ledge	2	
Shale, dark gray to black, alternating with bands of laminated, fine-grained, yellow sand	3	
Shale, dark gray to black, when moist	9	6
Sandstone, soft and incoherent, yellow	1	
Unexposed to river level	27	
Total	108	6

In the vicinity of Long Lake, in southeastern Burleigh County, and in the railroad cuts along the Linton Branch of the Northern Pacific, in northern Emmons County, the sandstone and shales of the Lance formation are well exposed, and they outcrop at a number of points about Linton. The eastern boundary can be determined only approximately on account of the heavy mantle of drift, which covers the bed-rock.

The Lance formation of south-central North Dakota, as shown on the foregoing pages, consists of three members: an upper sandstone about one hundred feet thick, a middle member composed of dark shales with a few sandstone layers and having a thickness of 200 to 250 feet, and a lower member made up of shales and sandstone in alternating layers. This latter member has a thickness of 350 feet or over, and the maximum thickness of the entire Lance formation is probably not far from 700 feet in this region.

Fossils occur sparingly in this area. A portion of the tibia of

Triceratops[1] was found at a horizon about 150 feet above the Fox Hills sandstone, and in 1908 Dr. T. W. Stanton collected dinosaur bones a few miles north of the mouth of the Cannon Ball River. These were identified as Ceratopsia and Trachodon, and came from beds approximately 100 feet above the Fox Hills sandstone.[2]

Fig. 5.—The Lance beds exposed in bluff of Little Missouri River near mouth of Bacon Creek, Billings County, North Dakota. Shows many concretions.

Little Missouri area.—Along the Little Missouri River in the extreme southwestern corner of North Dakota the Lance Beds are excellently shown in the bluffs and badlands bordering the valley. In going down the valley from Marmarth to Yule, many good outcrops appear and one passes from near the base to the top of the formation (Fig. 5). It is seen to be composed mostly of alternating beds of shale and soft sandstone, which have a notably dark and somber aspect in marked contrast to the yellow and light gray colors of the overlying Fort Union. The prevailing color

[1] Identified by Mr. C. W. Gilmore.

[2] *Proc. Wash. Acad. Sci.*, XI, No. 3 (1909), 250.

is dark gray, but weathered surfaces, especially when moist, frequently have a greenish gray or olive color. Beds of brown, carbonaceous clay shale are very common and conspicuous. The strata also contain much dark brown, ferruginous material, occurring both in thin seams and concretions, the latter being most numerous at certain horizons, and fragments of these cover the slopes in many places. Great numbers of sandstone concretions are present, some small, and others eight or ten feet in diameter.

Only thin beds of coal, not over eighteen inches thick or less, occur in the lower 300 feet or more of the Lance formation. Thus, in the 250 feet of strata exposed at the mouth of Bacon Creek there is practically no coal, the thickest bed being fifteen inches, and the same is true for all the Lance shales and sandstones exposed along the Little Missouri from the Pretty Buttes, five miles below Marmarth, to the South Dakota line. But in the upper portion of the formation, thick beds of lignite are found in many places. In the vicinity of Yule, five or six coal beds are present in the upper part of the member, and the coal of Bacon and Coyote creeks occurs at about the same horizon.

The basal beds of the Lance formation, together with the underlying Fox Hills sandstone, are well exposed on Little Beaver Creek, several miles southwest of Marmarth, and the relation of the two has already been described in connection with the Fox Hills.

The massive sandstone forming the top of the latter is seen to have undergone erosion before the deposition of the very carbonaceous and argillaceous, brown and black sandstone, which shows cross-lamination. Some of the depressions have been eroded to a depth of six feet below the adjoining elevations (Fig. 6).

The uneven surface of the Fox Hills shown here is perhaps due to contemporaneous erosion, and practically continuous deposition may be represented in this locality, as on the Cannon Ball River. The thickness of the Lance beds in southwestern North Dakota is approximately 600 feet. It is not possible here to divide them into three members, since the upper sandstone and the middle shale member are absent, and the strata are composed throughout of rapidly alternating shales and sandstones.

Plant remains are by no means as abundant in the Lance for-

mation as in the Fort Union, and in most localities they are quite rare. The following species were collected in the upper portion of the Lance beds near Yule:[1]

Taxodium occidentale Newb.
Populus amblyrhyncha Ward.
Platanus Haydenii Newb.
Juglans rugosa? Lesq.
Hicoria antiquora (Newb.) Kn.
Sapindus affinis Newb.
Viburnum Whymperi Heer.
Trapa microphylla Lesq. of Ward.
Cocculus Haydenianus Ward.

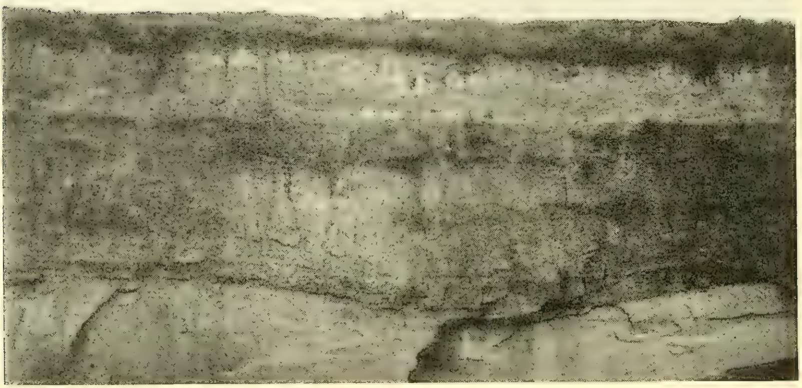

FIG. 6.—The eroded surface of the Fox Hills sandstone overlain by dark, carbonaceous beds of the Lance formation. Little Beaver Creek, Bowman County, North Dakota.

According to Dr. Knowlton, these plants belong without question to a Fort Union flora. Near the mouth of Bacon Creek in the lower part of the Lance formation and associated with the dinosaur bones, a Ficus fruit was found. The same species is present in the beds on Hell Creek and at Forsyth, Montana.

Five miles southwest of Yule, in section 16, T. 135 N., R. 105 W., an oyster bed was found in the summer of 1907. It was about 180 feet above river level or some 500 feet above the base of the formation and most of the shells were near the middle of a layer of brown carbonaceous shale seven feet thick, with a coal bed

[1] Identified by Dr. F. H. Knowlton.

below and another above. A band six to eight inches thick is in places closely packed with the shells, which Dr. T. W. Stanton, who visited the locality in the summer of 1909, refers to *Ostrea subtrigonalis* and *Ostrea glabra*. While in the Little Beaver Creek region there was an abrupt change at the close of Fox Hills time from marine to land or fresh-water deposits, as Dr. Stanton points out, this oyster bed is evidence that in this neighboring area

marine or at least brackish water conditions continued for some time after non-marine deposition began. . . . . Such an oyster bed must have been formed in tidal waters connected with the sea, and its presence here argues strongly for the assumption that the underlying portion of the Lance formation was formed near sea level so that a slight downward movement permitted temporary admission of brackish water into the low lying swamps and marshes in which coal was forming. It is, therefore, most probable that the abrupt change from marine to fresh-water and land conditions seen near Marmarth is purely local, and that the eroded surface at the top of the Fox Hills does not represent a time interval of any geologic importance.[1]

The lower portion of the Lance formation contains many dinosaur bones among which those of Triceratops are most abundant. Many were found in the badlands at the mouth of Bacon Creek. Mr. Gilmore, who examined them, referred some tentatively to the species *Triceratops horridus* (?) and one belonged to the genus Trachodon.

Yellowstone Valley area.—The Lance beds, as already stated, are found along the valley of the Yellowstone for a distance of nearly 150 miles, or from the vicinity of Forsyth to a point about fifteen miles below Glendive. They are well exposed near the latter town, and in the vicinity of Iron Bluff, about ten miles southwest, the following section occurs:

	Feet
8. Coal bed, burned, but probably 6 feet thick	
7. Shale with a few thin beds of sandstone; one of these sandstone layers 20 feet above the base contains many plants	150
6. Sandstone, massive, gray	40
5. Shale and sandstone; a few fossil plants at base	160
4. Sandstone, massive, white; most prominent stratum in the region	35
3. Sandstone, brown, forms summit of Iron Bluff	75
2. Shale and sandstone	75
1. Shale, dark, with calcareous concretions carrying abundant marine shells (Pierre); exposed to river level	100
Total	635

[1] *Am. Jour. Sci.*, XXX (September, 1910), 183.

The succession of strata in the above section is unlike that of any other found in eastern Montana or North Dakota, which includes the beds from the Pierre to the Fort Union, in that the Fox Hills appears to be missing. At least, no invertebrates have been found in Nos. 2 and 3, and the plants are too fragmentary to be determined, so that the age of these 150 feet of sandstone and shale overlying the Pierre is in doubt. They have the stratigraphic position of the Fox Hills, but in the absence of Fox Hills fossils it is perhaps best to include them provisionally with the Lance formation.

In the white sandstone (No. 4) Dr. A. C. Peale collected the following plants:[1]

Populus cuneata Newb.
Ginkgo adiantoides (Unger) Heer.
Quercus sp.
Ficus trinervis Kn.
Lauraceous leaf.
Ficus or Sapindus sp.
Viburnum sp.
Viburnum whymperi Heer.

In the vicinity of Glendive, Barnum Brown records having found fragments of Triceratops and Trachodont dinosaurs.[2]

At Miles City, the Lance formation rises 500 feet above the Yellowstone River and in Signal Butte and the Pine Hills, several miles east of town it is overlain by 200 feet and more of Fort Union shales and sandstones. In this region, as elsewhere, the prevailing color of the Lance beds is dark gray, and they present the usual contrast to the light yellow and ash gray of the Fort Union. The formation here contains several workable coal beds which supply coal to Miles City.

The following plants were obtained from the Lance formation in the bluffs of the Yellowstone across from Miles City at an elevation of from 115 to 125 feet above the river:[3]

Populus cuneata Newb.
Populus amblyrhyncha Ward.
Populus nervosa elongata Newb.
Populus rotundifolia Newb.
Corylus americana Walter.
Hicoria ? sp.
Platanus sp.
Cornus Newberryi Hollick.
Nelumbo n. sp.
Onoclea sensibilis fossilis Newb.
Trapa ? microphylla Lesq., as identified by Ward.
Corylus rostrata Aiton.

[1] *Bull. Am. Mus. Nat. Hist.*, XXIII (1907), 823.

[2] *Proc. Wash. Acad. Sci.*, XI, No. 3, p. 197.

[3] Identified by Dr. F. H. Knowlton.

A large number of plants collected from the same formation in the Miles City region are listed by Dr. Knowlton in his discussion of this area.[1]

The Lance beds extend up the Tongue river about 50 miles above its mouth, or to within about ten miles of Ashland.[2]

That they extend up the Powder River at least twelve miles above Hackett is indicated by the finding of part of a Triceratops skeleton at that point by Barnum Brown, the bones occurring in dark shale near river level.[3] There is also evidence for believing that the Lance formation appears along the Powder River valley almost if not quite as far south as the Wyoming line, Mr. E. S. Riggs, of the Field Museum of Natural History, having found on the East Fork of the Little Powder River "a weathered skeleton of Trachodon, partial skulls of Ceratopsia and fragments of a large carnivorous dinosaur, probably a Tyrannosaurus. The formation was thence traced along the east bank of Powder River from Powderville to a point on Sheep Creek some miles northeast of Mizpah."[4]

Missouri Valley area.—In Dawson and Valley counties, Montana, the Lance formation is exposed over a large area, bordering the Missouri River from the Musselshell on the west to the station of Brockton on the east. The beds are particularly well shown in the badlands formed by the many tributaries of the Missouri from the south. Among these is Hell Creek, which enters the river south and west of Glasgow, and the formations occurring in this vicinity have been studied and described by Mr. Barnum Brown.[5] A massive brown sandstone here forms the basal member of the Lance formation, whereas in south-central North Dakota it is the upper member which is sandstone. The thick black shale member is also absent, but in general there is a strong resemblance between the beds of the two localities.

[1] *Proc. Wash. Acad. Sci.*, XI, No. 3 (1909), 188–90.

[2] C. H. Wegemann, "Notes on the Coals of the Custer National Forest, Montana," *Bull. U.S. Geol. Surv., No. 381* (1909), 104.

[3] *Bull. Am. Mus. Nat. Hist.*, XXIII (1907), 823.

[4] *Proc. Wash. Acad. Sci.*, XI, No. 3 (1909), 204.

[5] *Bull. Am. Mus. Nat. Hist.*, XXIII (1907), 823–45.

The following section is exposed in the valley of Hell Creek:

	Feet
7. Shale and sandstone, light gray and yellow, containing beds of coal 2 to 11 feet thick, and also many plant remains. Fort Union	115
6. Shale and sandstone, similar in appearance to No. 4, but contains no dinosaur bones	100
5. Coal bed, persistent, has been traced a distance of 25 miles	6
4. Shale and sandstone with prevailing dark gray color; contains many brown, carbonaceous layers and some beds of coal. Contained in this member are two fairly persistent sandstone horizons from 15 to 20 feet thick, and with 30 to 40 feet of shale between. These sandstones contain many large brown sandstone concretions	210–260
3. Sandstone, the basal member of the Lance formation. Coarse-grained and rather soft; characterized by its massiveness, irregularity of bedding, the great number of large sandstone concretions, and its cross-lamination. Yellow and brown in color	100
2. Shale, more or less sandy, with some sandstone, light gray to buff. Fox Hills	100
1. Shale, dark gray, with fossiliferous calcareous concretions near the top. Pierre. Exposed above creek	150

Nos. 3 and 4 of the above section, which belong to the Lance formation, have yielded many dinosaur bones, including Triceratops, Trachodon, and Tyrannosaurus; also the remains of Camposaurus, crocodiles, and turtles, together with a few mammal teeth. Plant remains are rare in this region, but Mr. Brown found the following associated with the skeleton of a dinosaur:[1]

Sequoia Nordenskioldii Heer.	Populus amblyrhyncha Ward.
Taxodium occidentale Newb.	Quercus sp.
Ginkgo adiantoidis (Ung.) Heer.	Ficus artocarpoides Lesq.
Populus cuneata Newb.	Sapindus affinis Newb.

A large number of invertebrates were also secured from the Lance beds, including many species of Unios.

The age of No. 6 of the above section, which corresponds to Barnum Brown's "lignite beds," is uncertain since it contains almost no fossils. Largely on the basis of the lack of dinosaur bones in this member, Mr. Brown separates it from his Hell Creek beds and regards it as probably Fort Union. He correlates it, however, and correctly, with the 400 feet of strata exposed at

[1] *Proc. Wash. Acad. Sci.*, XI, No. 3, p. 185.

Miles City, and it is known that these belong to the Lance formation. The beds of No. 6 also contain the many brown, carbonaceous layers, so characteristic of the Lance formation in many localities, as well as a number of coal beds, which are also found in that formation in certain areas, as already shown. There would seem to be seme ground, therefore, for including this member with the underlying Lance beds rather than with the typical

Fig. 7.—The Fox Hills (A) and Lance (B) formations exposed on Hell Creek, Montana.

Fort Union, to which it bears little resemblance. If so included the Lance formation in this region would have a thickness of about 400 feet. According to Brown there is an unconformity at its base, which shows near the Cook ranch on Crooked Creek, and also on Hell Creek. Neither of these points was visited by the writer, and where the top of the Fox Hills was seen no evidence of a long erosion interval was observed, though such may be present in the localities above mentioned (Fig. 7).

The Lance formation appears to grow thinner toward the north-

east, since on the Fort Peck Indian Reservation, according to C. D. Smith, "about 200 feet of somber-colored sands and clays, with numerous carbonaceous layers and a few beds of impure lignite, overlie the Fox Hills sandstone."[1] In that region there is no apparent unconformity between the Fox Hills and the Lance beds, the two so grading into each other that their contact is very indefinite. Good exposures of the latter formation are found on Cottonwood Creek and Poplar River in the Fort Peck Indian Reservation, and in the badlands south of the Missouri River.

The Lance formation lies near the boundary line between the Cretaceous and Tertiary, and for this reason it is difficult to determine to which of these systems it should be referred. In most places where the contact has been observed it is seen to rest conformably on the Fox Hills sandstone, and everywhere passes conformably into the Fort Union above. Deposition was thus continuous from Cretaceous time on into the Tertiary, and there is no break in the sedimentation which might form a line of separation. On stratigraphic grounds, therefore, the Lance formation is as closely related to the Fox Hills sandstone below as to the Fort Union above, and we are forced to depend on the fauna and flora for the determination of the age.

According to Dr. Knowlton, 193 forms of plants have been found in these beds and of these, 84 species have been positively identified.[2] Since the greater number of these plants (68 species) are common to the Fort Union, he considers the Lance beds the lower member of the Fort Union formation, and, therefore, of Tertiary age. The writer formerly held the same opinion regarding the age of the Lance formation, but on the basis of its vertebrate fauna, including many dinosaurs, and its conformity with the underlying Fox Hills, there is much ground for the belief held by Dr. Stanton and others that the Lance beds should be regarded as of Cretaceous age. But to whichever system they are ultimately referred, it is at least certain, as stated above, that these beds lie near the border line between the Cretaceous and Tertiary. They have the

[1] *Bull. U.S. Geol. Surv., No. 381* (1909), 39.

[2] *Proc. Wash. Acad. Sci.*, XI, No. 3 (1909), 219.

same stratigraphic position as the Laramie formation, with which they correspond in whole or in part.

FORT UNION FORMATION

The Fort Union is one of the most important and best known formations of the Northwest. It covers a vast area east of the Rocky Mountains, stretching from Wyoming to the Arctic Ocean in the valley of the Mackenzie River, and including several Cana-

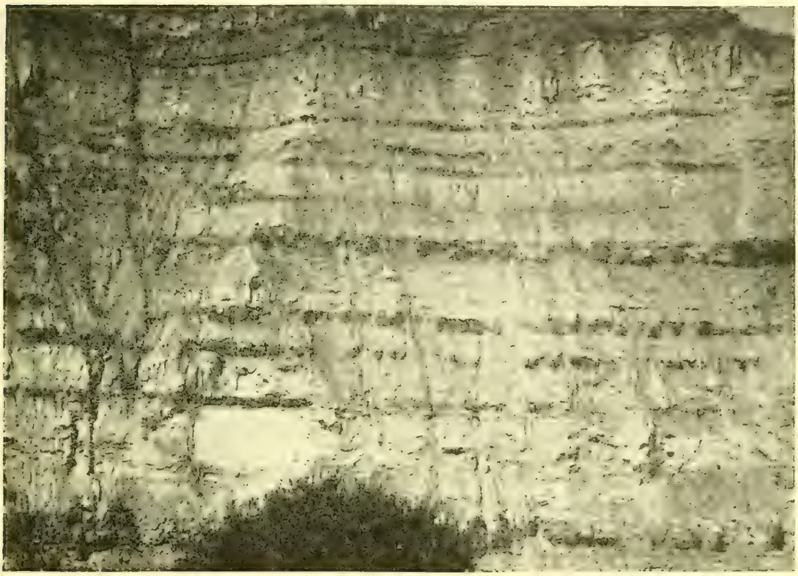

FIG. 8.—Outcrop of Fort Union on Beaver Creek, northern Billings County, showing ten coal beds. The thickest measures four feet, four inches.

dian provinces, much of western North Dakota, eastern Montana, northwestern South Dakota, and central and eastern Wyoming.

The name Fort Union was first used by Dr. F. V. Hayden in 1861 to designate the group of strata, containing lignite beds, in the country around Fort Union, at the mouth of the Yellowstone River, and extending north into Canada and south to old Fort Clark, on the Missouri River above Bismarck. It is a fresh-water formation and is composed of clay shales alternating with soft, rather fine-grained sandstone and containing many beds of lignite.

The Fort Union is remarkably uniform in color, composition, and appearance throughout the region under discussion. The prevailing color is either a light ash gray or yellow, but in places the beds are nearly white. In Billings County, North Dakota, an upper member of the formation appears in the tops of the higher ridges, divides, and buttes, and resembles somewhat the Lance beds in its dark gray color and its many brown ferruginous, sandstone concretions. The lower member constitutes the typical yellow

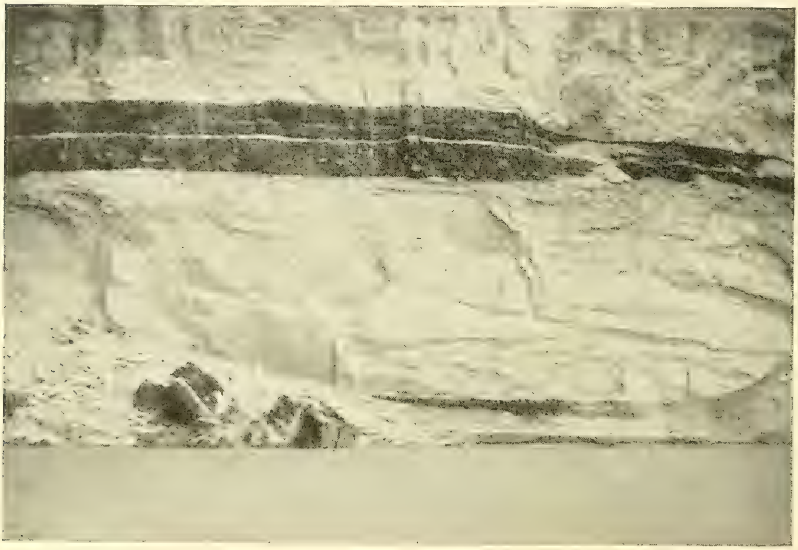

FIG. 9.—Two coal beds on Little Missouri River in northern Billings County, North Dakota. Upper bed is ten feet thick, the lower is near river level.

and light gray Fort Union and this is the only one present over most of the region. Where both occur, the contrast between the upper and lower members is so well marked and their contact so clearly defined that it can be readily distinguished even at a distance and traced without difficulty, wherever it is exposed. Over nearly one-half of Billings County a thick coal bed or layer of clinker formed by the burning of the coal occurs just at the contact. The strata forming both members of the Fort Union are seen along the Northern Pacific Railroad between Fryburg and Medora,

North Dakota. From the former station to the siding at Scoria, the upper member is well shown in the badlands on either side, while between Scoria and Medora the lower member appears.

Over a large area in southwestern North Dakota, the Fort Union is formed in part of white, sandy clays and very pure plastic clays, which differ from any of the beds found elsewhere. They

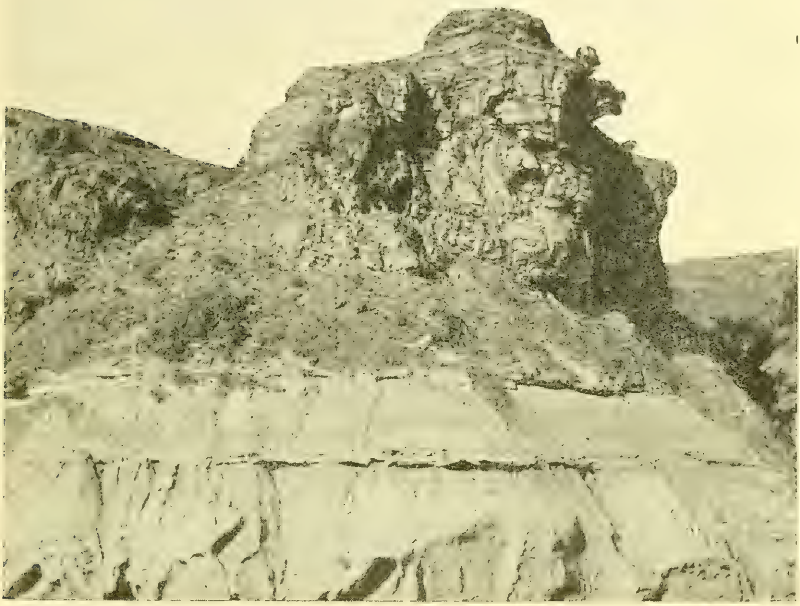

FIG. 10.—A mass of burned clay or clinker formed by the burning of a thick coal bed. Mouth of Deep Creek, Billings County, North Dakota.

occur in Stark and Dunn counties and adjoining portions of the surrounding counties, where they are restricted to the tops of the higher ridges and divides or to an elevation of from 2,450 to 2,600 feet above sea-level. Near their eastern border they lie about 600 feet above the base of the Fort Union and their maximum thickness is 150 feet. These white, sandy clays are well seen near Dickinson and Gladstone, and several miles north of Hebron.

The Fort Union formation everywhere contains numerous

beds of lignite (Fig. 8). These vary in thickness from an inch and less to thirty-five feet, beds six, eight, and ten feet thick being common (Fig. 9). Coal is much more liable to be present in the Fort Union than in the underlying Lance formation, for the latter is practically barren of coal in many localities and over large areas. One rarely finds an outcrop of the former where several hundred feet of strata are exposed that does not contain

FIG. 11.—A burning coal bed. The surface over the coal has settled many feet and the ground is broken by wide cracks from which gases escape. Typical Fort Union beds in background.

at least one or more coal beds. These range from top to bottom of the formation and do not appear to be confined to any particular horizon or horizons. The aggregate thickness of the twenty-one coal beds of southwestern North Dakota which are four feet and over is 157 feet.

One of the most conspicuous features of the Fort Union is the vast quantity of burned clay or clinker produced by the heat of the burning coal beds (Fig. 10). This has been sufficient to burn

the overlying clays to a red or salmon-pink color and in many places to completely fuse them to slag-like masses. The beds of clinker vary in thickness from five or six to forty feet, or over, and some of them can be traced many miles in the bluffs bordering the valleys and in the ridges and divides, while large numbers of the lower buttes are capped with these protecting layers (Fig. 11).

There are great numbers of excellent exposures of the Fort

FIG. 12.—The Tepee Butte bluff of Little Missouri River, 584 feet high, showing dark colored upper member and light colored typical Fort Union below.

Union beds in the wide belt of badlands bordering the Little Missouri valley from a few miles below Yule to the mouth of the river, a distance of nearly 200 miles; numerous good outcrops are also found in the exceedingly rough badlands which border the Yellowstone on the east between Glendive and its mouth. While outcrops are quite abundant throughout the region under discussion, nowhere are there such favorable conditions for the study of the Fort Union formation as in the two areas just mentioned.

The following section is given both because it is typical of this formation, and also since it includes the greatest thickness of beds seen in any single outcrop. It is exposed in a high steep bluff of the Little Missouri which is surmounted by the Tepee Buttes, and is one and a half miles above the mouth of Deep Creek (Fig. 12).

	Feet	Inches
Sandstone, to top of Tepee Buttes	35	
Shale, sandy, yellow	17	8
Coal	4	6
Shale, dark gray	21	6
Sandstone, brown, with many ferruginous concretions	23	
Shale, yellow	31	9
Shale, carbonaceous, brown		9
Coal	6	3
Shale, gray	3	2
Sandstone	11	
Shale, dark gray	7	2
Coal		2
Shale, dark	3	5
Coal		7
Shale, carbonaceous, brown	1	
Coal	2	
Shale, carbonaceous, brown		2
Coal	3	
Sandstone, passing into shale	23	10
Shale, yellow and brown, sandy in part	24	5
Sandstone, brown	6	4
Coal		3
Shale, yellow and brown	7	4
Sandstone, passing into shale	18	
Shale and some coal	1	2
Sandstone	9	
Coal		6
Shale, carbonaceous, brown		8
Coal		1
Shale, brown		2
Coal		1
Shale, brown and gray, sandy	23	
Coal		3
Shale		9
Coal		5

	Feet	Inches
Shale, brown		6
Coal	1	7
Shale	1	2
Coal		3
Shale, sandy in part	18	
Coal		6
Shale, yellow	1	
Coal		2
Shale, sandy	8	5
Shale, brown		2
Coal	1	6
Shale, carbonaceous, brown	1	
Sandstone, argillaceous, yellow	13	7
Coal		8
Shale, sandy, yellow	5	10
Shale, black		3
Sandstone	6	2
Shale, black		2
Shale, sandy, yellow and brown	6	
Sandstone, argillaceous, yellow and gray	19	
Shale, yellow	7	1
Sandstone, yellow	4	
Shale, brown and yellow	10	10
Sandstone, gray	2	6
Shale, brown	2	8
Coal	2	2
Shale, brown, carbonaceous	1	
Shale, yellow, sandy	1	
Sandstone	3	3
Coal		2
Shale, sandy, yellow	2	
Sandstone, yellow	4	7
Coal	1	4
Shale, brown		3
Coal		6
Shale		6
Coal	9	4
Shale, brown		2
Shale, sandy, yellow	5	
Sandstone, yellow	26	
Coal	2	2
Shale		2

	Feet	Inches
Coal	2	8
Shale	1	
Coal		8
Shale, brown		3
Sandstone, and sandy shale, yellow	20	
Shale, brown		6
Coal		10
Shale, brown		6
Coal	1	6
Shale, brown		2
Coal	3	2
Shale		1
Coal	1	8
Shale, yellow and dark gray	20	
Sandstone, yellow	49	6
Coal		4
Sandstone and sandy shale	1	3
Shale, dark		10
Coal	1	8
Sandstone, yellow, to river level	12	
Total	584	

The large number of coal beds occurring in the Fort Union is well shown in the above section. The base of the section is probably not over 100 feet above the Lance beds, which disappear beneath river level not many miles below. The outcrop thus includes not only a large portion of the lower yellow and light gray member of the Fort Union, but also about 183 feet of the upper, dark-colored member. Where the uppermost beds of the formation are found, as on top of such high buttes as Sentinel, Flat Top, Bullion, and Black, they are seen to consist of a rather hard sandstone 80 to 100 feet thick. This rock forms vertical cliffs about the summits of these buttes, and huge blocks breaking off from time to time accumulate at the base of the cliffs in great talus heaps. On Sentinel Butte and the White Buttes, the White River beds are seen resting directly on this uppermost sandstone of the Fort Union.

The maximum thickness of the Fort Union is not far from 1,000 feet in western North Dakota, but over most of the region it has undergone great erosion and from large areas hundreds of feet

have been removed. It was only by the erosion of this entire formation that the Lance beds have been exposed along the Yellowstone and Missouri rivers and elsewhere, since the Fort Union formerly covered the entire region.

The Fort Union beds, which are early Eocene in age, contain a flora of nearly 400 species, and a fauna comprising both invertebrates and vertebrates. The plants contained in the following lists were found in the yellow and light gray beds forming the lower part of the formation. Most of them occurred either in concretions or in layers of sandstone.[1]

NEAR MEDORA, NORTH DAKOTA

Sequoia Nordenskioldi Heer.	Populus daphnogenoides Ward.
Populus cuneata Newb.	Populus glandulifera Heer.
Ulmus planeroides Ward.	Planera microphylla Newb.
Populus Richardsoni Heer.	Carpites n. sp.
Populus amblyrhyncha Ward.	Taxodium occidentale Newb.
Sapindus grandifoliolus Ward.	Diospyros brachysepala Al. Br.
Viburnum antiquum (Newb.) Hol.	Asplenium tenerum.

MOUTH OF DEEP CREEK, SOUTHERN BILLINGS COUNTY, NORTH DAKOTA

Viburnum Newberrianum Ward.	Viburnum asperum Newb.

NORTHERN BILLINGS COUNTY, NORTH DAKOTA

Equisetum sp.	Viburnum antiquum (Newb.) Hol.
Viburnum Newberrianum Ward.	Viburnum Whymperi ? Heer.
Diospyros—may be D. ficoidea Lesq. or new.	Corylus rostrata ? Ait.
	Taxodium occidentale Newb.
Platanus nobilis Newb.	Pterespermites Whitei ? Ward.

WESTERN BURLEIGH COUNTY, NORTH DAKOTA, NEAR THE BASE OF THE FORT UNION AT ELEVATION OF ABOUT 400 FEET ABOVE MISSOURI RIVER

Populus daphnogenoides Ward.	Platanus Haydenii Newb. Young leaf.
Populus amblyrhyncha Ward.	Viburnum sp.
Populus cuneata Newb.	
Aralia notata Lesq.	

CENTRAL BURLEIGH COUNTY, NORTH DAKOTA, NEAR BASE OF THE FORT UNION

Populus daphogenoides Ward.	Platanus nobilis Newb.
Populus sp. ?	Grewiopsis populifolia Ward.
Populus amblyrhyncha Ward.	Euonymus ? sp.

[1] The plants were identified by Dr. F. H. Knowlton.

WESTERN DAWSON COUNTY, MONTANA

Onoclea sensibilis fossilis Newb.
Populus cuneata Newb.
Leguminosites arachioides Lesq.
Celastrus pterospermoides Ward.
Populus amblyrhyncha Ward.
Populus daphnogenoides Ward.
Populus arctica Heer (as identified by Lesquereux).
Populus smilacifolia Newb.
Populus nebrascensis Newb.
Populus genatrix Newb.
Populus speciosa Ward.
Cocculus Haydenianus Ward.
Platanus Haydenii Newb.
Plantanus nobilis Newb.
Sequoia Nordenskioldii ? Heer.
Thuja interrupta Newb.
Glyptostrobus europaeus (Brongn.) Heer.

BASE OF THE FORT UNION IN SIGNAL BUTTE, FIVE MILES EAST OF MILES CITY, MONTANA

Taxodium occidentale Newb.
Sequoia Nordenskioldii Heer ?
Glyptostrobus europaeus (Brongn.) Heer.
Populus ? sp. ? cf. genatrix Newb.
Populus, possibly P. acerifolia Newb.
Betula, sp. new ?
Corylus rostrata Aiton.
Corylus americana Walter.
Planera.
Hicoria antiquorum (Newb.) Knowlton.
Hicoria ? sp. new.
Celastrus ovatus Ward.
Sapindus grandifoliolus Ward.

The Fort Union beds contain many fresh-water shells, among which the following species were collected:[1]

NORTHERN BILLINGS COUNTY, NORTH DAKOTA

Campeloma producta White.
Viviparus retusus.
Viviparus leai M. & H.
Campeloma multilineata M. & H.
Thaumastus limnaeiformis M. & H.
Corbula mactriformis M. & H.
Viviparus trochiformis M. & H.
Sphaerium formosum M. & H.
Bulinus longiusculus M. & H.
Micropyrgus minutulus M. & H.
Hydrobia.

SOUTHERN BILLINGS COUNTY, NORTH DAKOTA

Unio priscus M. & H.

NORTHEASTERN CORNER OF MORTON COUNTY, 350 FEET ABOVE MISSOURI RIVER

Corbula mactriformis M. & H.
Campeloma multilineata M. & H.
Viviparus trochiformis M. & H.

[1] Identified by Dr. T. W. Stanton.

WESTERN BURLEIGH COUNTY, ABOUT 350 FEET ABOVE THE MISSOURI RIVER

Viviparus retusus M. & H.
Campeloma producta White.
Campeloma multilineata M. &. H.
Unio sp. fragments.
Corbula mactriformis M. & H.
Viviparus multilineata M. &. H.

Vertebrate fossils are rare in the Fort Union formation. In western North Dakota, near Medora, a few bones were collected which were identified by Mr. J. W. Gidley as those of fishes, turtles, and the aquatic reptile, *Champsosaurus laramiensis*. The latter has been found by Mr. Barnum Brown in the Lance beds of the Hell Creek region, and also in the "lignite beds" just below the typical Fort Union.[1]

WHITE RIVER BEDS

The White River beds of the Oligocene occupy three small areas in southwestern North Dakota, and several in the southeastern corner of Custer County, Montana. The beds of this group are found in White Butte, in southeastern Billings County, where they cover an area from eight to ten square miles in extent, forming the highest portion of the divide at the head waters of the North Fork of the Cannon Ball River and Deep and Sand creeks. Erosion has here left two ridges about two miles apart, with an elevation of 300 to 400 feet above the surrounding plain. Three miles to the west, on the opposite side of the valley of Sand Creek, Black Butte rises 450 feet above the creek, being capped by the same sandstone as that forming the top of the other high buttes of the region. But the beds of the White River group are wanting on Black Butte, although occurring at a considerably lower level only three miles to the east. In White Butte they are, however, seen resting directly on this upper sandstone of the Fort Union, which outcrops at several points near the base of the western slope of the western ridge and also at its northern end. This sandstone here dips strongly to the east so that within a distance of three miles its dip carries it from the top of Black Butte to the base of the ridge on the opposite side of the valley, where it is over 200 feet lower.

[1] *Bull. Am. Mus. Nat. Hist.*, XXIII (1907), 835.

The following is a general section of the White River beds as they occur in White Butte:

	Feet	Inches
11. Sandstone, rather fine-grained, light greenish gray in color, weathering into a greenish sand; to top of White Butte	105	
10. Clay, gray to light greenish color	20–25	
9. Clay, hard and compact, calcareous, light gray, almost white; forms hard ledges which make low vertical cliffs toward the top of the butte, and weathers very irregularly	34	
8. Clay, dark gray, calcareous, the line of separation between this clay and No. 7 is sharp and distinct, the clay being considerably darker than the underlying sandstone	46	
7. Sandstone, light gray, rather coarse-grained	20	
6. Sandstone, very coarse-grained and pebbly; in places the pebbles are so abundant as to form a conglomerate. Shows cross-lamination. Pebbles composed of quartz, silicified wood, many varieties of igneous rock, among which porphyry is common. Pebbles range in size up to 2 and 3 inches in diameter	26	
5. Clay, very light gray, slightly sandy	5	
4. Sandstone, light gray, very fine-grained and argillaceous	5	4
3. Clay, light gray to white, slightly darker than No. 2; contains some fine sand	10	6
2. Clay, very white and pure	6	6
1. Clay, white, containing some fine sand, hard and very tough when dry; rests directly on the sandstone of the Fort Union	14	4
Total	298	

In No. 8 of the above section was found the skull of an extinct species of ruminant, *Eporeodon major* (?), which is found in the Oreodon beds of the Oligocene.[1]

It will be seen from the section just given that the White River group is here composed of white clays at the bottom, on which rests a coarse sandstone which in places is filled with large pebbles; this is overlain by about 100 feet of calcareous clays which in turn are overlain by more than 100 feet of fine-grained, greenish sandstone (Fig. 13).

These deposits represent all three divisions of the White River group, the lower or Titanotherium beds, the middle or Oreodon beds, and the upper or Protoceras beds. In the foregoing section Nos. 1 to 7 probably belong to the lower, Nos. 8 to 10 to the middle, and No. 11 to the upper division.

[1] Identified by Mr. J. W. Gidley.

It was probably this same White Butte area which was discovered by Professor E. D. Cope in September, 1883. The discovery was announced in a letter written from Sully Springs, Dakota, and read before the American Philosophical Society. The following is a portion of this letter:

I have the pleasure to announce to you that I have within the last week discovered the locality of a new lake of the White River epoch, at a point in this Territory nearly 200 miles northwest of the nearest boundary of the

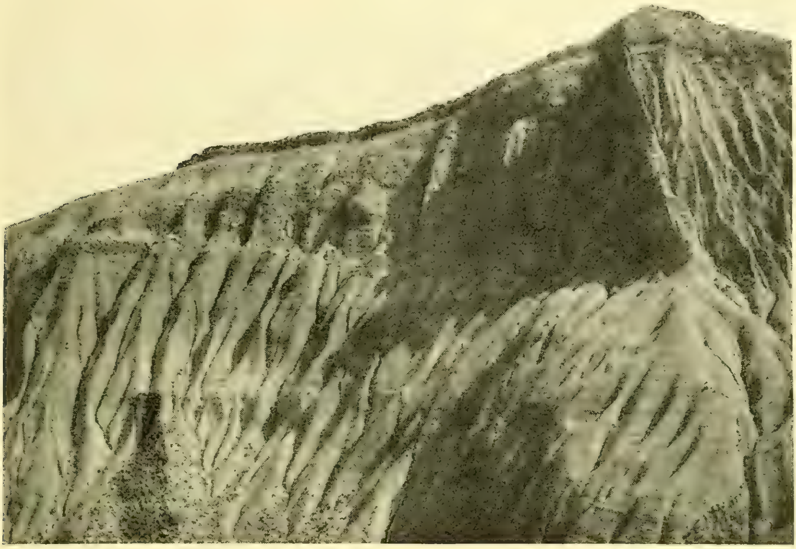

FIG. 13.—The coarse sandstone of the lower member of the White River beds in White Butte, Billings County, North Dakota, showing effects of rain erosion.

deposit of this age hitherto known. The beds, which are unmistakably of the White River formation, consist of greenish sandstone and sand beds of a combined thickness of about 100 feet. These rest upon white calcareous clay, rocks, and marls of a total thickness of 100 feet. These probably also belong to the White River epoch, but contain no fossils. Below this deposit is a third bed of drab clay, which swells and cracks on exposure to weather, which rests on a thick bed of white and gray sand, more or less mixed with gravel. This bed, with the overlying clay, probably belongs to the Laramie period, as the beds lower in the series certainly do.

Then follows a list of 20 species of vertebrates which were collected from this locality, including *Trionyx*, *Galecynus gregarius*,

Aceratherium, *Elotherium ramosum*, *Oreodon*, and *Leptomeryx*. The white calcareous clay below the upper sandstone is now known to carry fossils and the sand below this clay is probably to be included with the White River group. Professor Cope, in common with other geologists at that time, regarded the underlying beds as belonging to the Laramie, but as already stated, they are now on the evidence of their plant remains known to be Fort Union in age.

Mr. Earl Douglass spent some time in the White Butte locality during the summer of 1905, and has described in considerable detail the beds occurring here.[1]

In the middle member or Oreodon beds, he found the following fossils: *Ictops*, *Ischyromys*, *Palaeolagus*, *Merycoidodon culbertsoni*, *Leptomeryx evansi*, *Mesohippus*, *Hyracodon*, *Gymnoptychus*, *Eumys*, and *Aceratherium*.

Mr. Douglass discovered another deposit of White River beds about thirty miles north and east of White Butte, in Stark County. The area, which is known as the "Little Bad Lands," lies some twelve to sixteen miles southwest of Dickinson. All three divisions of the White River group are here present and a number of mammalian bones were collected.

The third locality in North Dakota where the Oligocene occurs is on top of Sentinel Butte, in northern Billings County, near the town of the same name. The beds are here seen resting conformably on the massive sandstone which forms the top of the Fort Union. The beds occur only on the northern end of Sentinel Butte and their maximum thickness is not over forty feet. They are clearly the remnants left by the erosion of a thicker and more extended formation which doubtless once covered a large area in this region. Where the strata are exposed in a low mound near the northwestern edge of the butte they are seen to be composed of light gray calcareous clay or marl, which contains, toward the top, beds of a nearly white, compact limestone. This limestone breaks readily into thin layers one-eighth to one-quarter of an inch thick, and some of the thicker layers become siliceous toward the center.

In one of the upper beds of this limestone are found the remains of two species of fresh-water fishes. These fossil fishes were first

[1] *Annals of the Carnegie Museum*, V, Nos. 2 and 3 (1909), 281–88.

discovered on Sentinel Butte by Dr. C. A. White, who visited the locality in 1882 and published an account of the deposit containing them. They were described by E. D. Cope as belonging to a new genus and were named by him *Plioplarchus Whitei* Cope and *Plioplarchus sexspinosus* Cope.

Since the fishes were not closely related to any previously described they did not serve to indicate the age of the beds in which they were found, but upon stratigraphic grounds Dr. White referred the strata to the Green River group of the Eocene, though he was by no means confident that this was their true position. In the light of more recent discoveries it seems much more probable that these beds on Sentinel Butte belong to the White River division of the Oligocene. It is now known that less than forty miles to the southeast are other deposits which rest directly on the upper sandstone of the Fort Union and which are known from their fossils to belong to the White River group. On the other hand, no beds of the Green River group are found any nearer than southwestern Wyoming and it is not at all likely that they ever extended this far north and east, while the White River beds cover considerable areas in South Dakota and Montana. The extensive erosion to which this region has been subjected during many ages, and which is known to have removed at least from 800 to 1,000 feet of strata over a large area, has left only a few remnants of the White River deposits.

In southeastern Custer County, Montana, in the district known as the Long Pine Hills between the Little Missouri River and Big Box Elder Creek, the White River beds are known to occur. They here have a thickness of at least 150 feet and are composed of fine-grained, greenish gray calcareous clay, soft, compact, white limestone, and calcareous clay. They resemble the White River beds of the Slim Buttes in South Dakota.

The Oligocene beds of North Dakota and Montana are believed to be in part lake deposits and in part river deposits. The lack of uniformity, the cross-bedding, and the coarseness of the materials in some portions of the formation are probably the result of deposition through river action. In other areas, as those of Sentinel Butte and Long Pine Hills, the materials were perhaps laid down in the more quiet water of a lake.

ON THE GENUS SYRINGOPLEURA SCHUCHERT[1]

GEORGE H. GIRTY

The genus Syringopleura has recently been proposed[2] for a brachiopod of the Spirifer group. It is typified by *Syringothyris randalli*, a species which Simpson described as possessing the internal structure of Syringothyris, along with a plicated fold and sinus. As is well known, Syringothyris is a Spirifer having a high area, a simple fold and sinus, and the characteristic "twilled cloth" sculpture. Internally there is developed a delthyrial plate, not to be confounded with the deltidial plates, which bears on the inner side the split tube characteristic of the genus. Typical Syringothyris is generally regarded as being an offshoot of the ostiolate Spirifers. Professor Schuchert gives the following reasons for establishing the genus:

> Another phylum originated in the Atlantic realm of the Appalachian province in *Spirifer randalli*, which also has a well-developed syrinx, but differs from *Syringothyris* of the Mississippian sea in having a strongly plicated fold and sinus. This stock must be separated generically from those of the Mississippian sea because of its different phyletic derivation, and for it is proposed the generic name *Syringopleura* (from *syrinx* and *pleura* or rib, having reference to the plicated fold and sinus), with *S. randalli* Simpson as the genotype.

Now I am compelled to question the validity of the genus Syringopleura on all the points advanced by Professor Schuchert.

In the first place, it seems highly probable that *S. randalli* does not possess the external peculiarity on which the genus was chiefly founded—the plicated fold and sinus. Syringothyroid shells are extremely abundant at the locality and horizon at which *S. randalli* was found, and I have examined a large number of specimens without in a single instance finding any which possessed the characteristic mesial plications. It is possible, of course, that the

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] *Am. Jour. Sci.*, XXX (1910), 224.

specimens coming before me all belonged to an abundant species, while *S. randalli* represents a different and much rarer one. The probabilities appear to me decidedly adverse to this hypothesis, however, and the following statement of Professor Schuchert's is in point. He writes of Syringothyris: "At no time, however, was there more than one species in a fauna, and all these are very much alike."

Thanks to the courtesy of the Academy of Natural Sciences of Philadelphia, I have been able to examine the type specimens of *S. randalli*, and this examination seems to bear out the opinion expressed above. The specimens sent me as the types are three in number (Nos. 9532, 9533, and 9534), only one of which, however, was figured in connection with Simpson's description.[1] It is an internal mold of a ventral valve. It is a fact that this specimen shows some very obscure, longitudinal markings at the bottom of the sinus, but it is also a fact that Simpson's drawing exaggerates these unpardonably.

When fossils are preserved as molds, the best opportunity to observe external characters is naturally afforded by molds of the outside. In the case of such species as *S. randalli*, internal molds of the dorsal valve are more satisfactory than internal molds of the ventral valve, because testaceous deposits on the inner surface of the shell which tend to obscure such external features as the plications were there less extensively developed. In internal molds of either valve the marginal portions afford better evidence than those near the umbo, because the secondary deposits were chiefly formed over the older parts of the shell. On the internal ventral mold which is the type specimen of *S. randalli*, the lateral costae are well shown except in the cardinal and umbonal areas. In this degree of expression they stop abruptly at the sinus. The anterior part of the sinus, where the costae, if present, would naturally be most conspicuously developed, is nearly, if not quite, smooth. The posterior part is occupied by the large umbonal scars. It is in the intermediate portion, where the test was probably still appreciably thickened, though less so than at the umbo, which was filled by the apical callosity, that the obscure radial markings can

[1] *Am. Phil. Soc., Trans.*, XV, 441, Figs. 1, 2.

best be seen. It is doubtful, however, whether these can be attributed to normal costation, which ought to be still better exhibited toward the front, rather than to inequalities in the rapidly thinning apical callosity, such as would be shown on the inside but not on the outside of the shell. Similar markings have been observed on other species of Syringothyris.

S. randalli occurs at the locality and horizon of the classic association of Syringothyris with *Spirifer disjunctus*.[1] *S. disjunctus*, or a species closely allied to it, occurs in equal abundance with the Syringothyris. Superficially the two types are distinguished by the fact that one has a simple fold and sinus and the other is plicated. Where this character is obscured, internal molds of ventral valves might be confused on casual observation, although one type possesses the syrinx and the other does not, and from the evidence in hand it seems almost certain that Simpson did thus confuse them, since one of the three type specimens of *Syringothyris randalli*, all of which are internal molds of ventral valves, is clearly a Spirifer. Although it does not show any surface characters whatever, it has the internal characters of and almost certainly belongs to the form commonly referred to *Spirifer disjunctus* in the Warren area. It appears plausible, therefore, that Simpson confused these two forms, and seeing well-marked plications on the fold and sinus of some specimens (*S. disjunctus*) felt justified in putting them into his description and into his figure, although they are only faintly suggested in the specimen from which the latter was drawn. Conclusive evidence can come only through an examination of the external mold of the type specimen, which is, of course, impossible; or less adequately through the discovery of other specimens unmistakably possessing the characters which *S. randalli* is said to have. But, for my own part, I am fairly satisfied that *S. randalli* is conspecific with the abundant associated Syringothyris which clearly has a simple fold and sinus.

Granting, however, that *S. randalli* does possess the plicated fold and sinus ascribed to it, let us examine into the argument by which this character is thought to justify the erection of a new genus.

[1] At Warren, Pa., at a horizon not far below the "Sub-Olean conglomerate" in a series of strata which I at one time proposed to call the Bradfordian group.

Professor Schuchert says that the erection of a genus is demanded by the fact that *S. randalli* has a different phyletic derivation from typical Syringothyris.[1] He is unfortunately not very explicit but he apparently derives typical Syringothyris from the ostiolate Spirifers and *S. randalli* (Syringopleura) from the aperturati. But it is a fair hypothesis that *S. randalli*, the hypothetized *randalli*, may have come from typical Syringothyris by the introduction of mesial plications at so early a period that in the imperfect condition of our record the two types seem to have developed nearly simultaneously. Or, a second hypothesis is not negligible, that the two may have sprung from some common ancestor, at present unknown, which was intermediate between the ostiolate Spirifers on the one hand (or whatever stock gave rise to Syringothyris) and Syringothyris and "Syringopleura" on the other. Professor Schuchert offers no evidence to support his theory of the derivation of *S. randalli* as against these two other possible hypotheses.[2]

But even if we grant that there is a species with the characters of *S. randalli* and that it is derived from some other group of Spirifers than that which gave rise to typical Syringothyris, a scrutiny into the line of reasoning which justifies the erection of a new genus from these premises will not, I believe, be without profit. The argument seems to be that, because *S. randalli* and typical Syringothyris belong to different phyla, therefore it is necessary to place them in different genera.

Originally and strictly the word phylum in biology is used for one of the larger divisions of the animal or vegetable kingdom, but it seems to be often employed for small groups standing in a line of genetic relationship. Thus *phylum* has a variety of meanings as regards comprehensiveness. We might even say that two Spirifers belonging to the same species but having different lines of descent for numerous generations belong to different phyla;

[1] Professor Schuchert is perhaps a little misleading in his expression which seems to limit Syringothyris to what he calls the Mississippian sea. Characteristic Syringothyris, of course, occurs not only associated with "*S. randalli*" near Warren, but at other localities and horizons in the same province.

[2] Still other hypotheses are possible, equally plausible with these. For instance, Hall and Clarke name a number of ostiolate Spirifers with incipient plications on the fold and sinus.

or we might say, as Professor Schuchert does, that two species representing different sections of the genus Spirifer belong to different phyla, and so on. Or, on the other hand, we might say that two genera, such as Spirifer and Athyris, belong to different pyhla, the one to the Spiriferoid stock, the other to the Athyroid. The meaning of the word depends largely on the viewpoint of the occasion, and any conclusion based on phyletic relationship is almost nil unless the writer defines what he means by phylum.

But let us consider what the force of such an argument really is in general terms. Put case that there are two Spirifers having other characters identical but differing in the height of the area or the length of the cardinal line or other similar characters and belonging to different phyla in the narrowest sense. We do not distinguish them as different genera or even different species, but say that these differences concern minor characters in which experience has shown that individual specimens differ from one another and vary at different stages of their growth. Put case again that we have two Spirifers, one with simple fold and sinus and pustulose sculpture, the other with plicated fold and sinus and finely reticulate sculpture, the two belonging to different phyla, in a broader sense. Here, again, we do not say, as Professor Schuchert does, that these species belong to different genera because they present important differences and have different phyletic relations, for the characters which they possess in common are such as we recognize as characteristic of the genus Spirifer and the differences are such as experience has shown to be useful only in specific discrimination. Again, suppose we have two generally similar oval brachiopods, one with internal spires, the other with an internal loop, and belonging to different phyla, in a still broader sense. We do not refer these types to different genera because they show such and such differences and belong to different phyla, for the differences are more important than those by which genera are determined and we place the species in still more widely separated groups. In other words, in such cases as these phyletic relationship enters little, if at all, into the determination of taxonomy. We go straight to the intrinsic characters of the form and according to the nature and degree of its resemblances and differ-

ences determine the order of its taxonomic relationship to other organisms.

On the other hand, let us suppose a rare case in which two forms are closely alike in most, or even all, of their mature characters but at the same time they can be shown to belong to different phyla. In this instance phyletic relationship has pre-eminent importance. We cannot place the two types in taxonomic relationship more close than the most remotely related of their ancestors. They must be placed in different genera (at least) if that phyletic relationship is generic; in different families if it is familiar; in different orders if it is ordinal, and so on. The logic of the situation seems, then, really to be that the phyletic argument only sets a limit on how close two types may stand in taxonomy, but does not enter into the determination of how far apart they may stand. That is based upon the physical characters of the mature individuals, not upon development or on the theories of investigators.

Returning now to the case of Syringothyris and Syringopleura, we find that the reputed ancestor of Syringothyris and the reputed ancestor of the suppositious Syringopleura are different species of the genus Spirifer. The phyletic argument,[1] if used aright, proves not that they must belong to different genera, but that they cannot be placed in the same species. If we base a determination of the relationship of Syringothyris and "Syringopleura" on their real, as distinguished from their speculative, characters, it would appear that they should be regarded as specifically, but not generically, distinct. At least, the peculiarities which are thought to distinguish Syringopleura are only rated as of specific import in the true Spirifers, and I do not see why they should be more important in the closely related syringophorous shells.

Therefore, it appears to me that Syringopleura is based on a

[1] The phyletic (phylic would be a much better term, but it unfortunately lacks authority) argument, which really only serves as a check upon misleading or misunderstood direct evidence, to prevent two forms from being classed in too close zoölogical categories, can rarely be used in paleontologic work because the phyletic relationship is seldom, if ever, more than speculative. Even if the trend of the evidence were correctly presented by him, the example set by Professor Schuchert in his proposed genus Syringopleura is fraught with danger, since it would make our zoölogic classification the prey of all sorts of theories, however ill-considered.

false premise, on an unsupported assumption, and on loose reasoning, and that it cannot stand.

If, as remarked by Professor Schuchert, several different types of Spirifer exhibit a tendency to develop the split tube, and if the development of this structure may be looked for in almost any high areaed member of the genus, far from adopting the course which he advocates of establishing a new genus for every such manifestation, I should feel that this series of facts materially lessened, if it did not destroy, the value of the syrinx as a generic character.

The function of the syrinx is not definitely known. The most probable explanation of its function, and the one adopted by Professor Schuchert, is that it is connected with the pedicle muscle. Even in typical Syringothyris there is no cogent reason for inferring that the soft parts possessed any structures different from those of Spirifer. If so, this typical structure of Syringothyris is probably to be regarded only as a result of excessive shell secretion, and it may well be questioned whether its employment as a generic character is any more justifiable than it would be so to employ the deposit of an apical callosity, with which the syrinx is perhaps a concurrent manifestation, or of a thick test with attendant deep muscular imprintation, a character regarded of little importance in other types of brachiopods. The tendency to develop an incipient syrinx in various groups of Spirifer contributes not a little to justify such a low estimate of the taxonomic value of this character.

PRELIMINARY NOTES ON SOME IGNEOUS ROCKS OF JAPAN. I[1]

S. KÔZU
Imperial Geological Survey of Japan

I. SODA-TRACHYTE

Localities.—Matsu-shima and Kakara-jima, two islets, six and a half kilometers northwest of the port of Yobuko, prov. Hizen, Kyûshû.

Occurrence.—As compact lava, associated with an alkaline feldspar-bearing basaltic rock.

Age.—Probably near the close of the Tertiary.

The following notes on the mineralogical and chemical characters were made from the specimen collected from Matsu-shima.

Megascopic characters.—The rock is blackish gray in color with semiwaxy luster, and by weathering easily changes to light brownish-gray with greenish tinge. The phenocrysts are of abundant feldspar, and are not easily distinguishable at a glance on fresh fracture surfaces, as their color is not white, but on weathered surfaces exposed to the washing of sea waves the minerals, being less attacked than the matrix, are as well marked as the coarse grains of quartz in weathered sandstone. The mode of weathering is a characteristic feature which enables us to distinguish the present rock from other rocks of the environs. The feldspar phenocrysts are thick tabular or sometimes stout prismatic, from 2 to 5 mm. in length, in rare instances 10 mm., and very light bluish-gray in color, for they contain abundant inclusions. The luster is not purely vitreous but slightly waxy. The groundmass is aphanitic and deep gray with light greenish tinge when freshly fractured, but the color soon changes from dark brownish-gray to light gray by weathering.

[1] Published by permission of the Director of the Imperial Geological Survey of Japan.

Microscopical characters.—The phenocrysts are of abundant euhedral, or sometimes subhedral, feldspar. Almost all of them are of anorthoclase, in which a small quantity of plagioclase is present, either as nucleus of zoning which can be seen very rarely, as perthite composing the faint perthitic structure, or as local patches in the anorthoclase crystals. The groundmass is holocrystalline, though small amounts of brown glass are locally present in the vicinity of feldspar phenocrysts. It consists essentially of prismoids of alkaline feldspar, elongated toward the axis *a*. They are arranged as in typical trachytic fabric. A smaller quantity of thin and long prismoids of aegirine-augite, crystals or grains of magnetite, and slender needles of apatite are disseminated through the feldspathic groundmass.

Feldspar, as phenocrysts, is soda-microcline, containing anorthite molecules, that is, calcium-bearing anorthoclase. The shape generally shows euhedral form, principally bounded by crystallographic faces (001), (010), and ($\bar{2}$01), and is thick tabular parallel to (010), or is very stout prismoid, or cuboidal. The characteristic habit is derived from its appearing in a rectangular form on the face (010), owing to the domination of the planes (001), ($\bar{2}$01), and (010), as is the case with feldspar in "Rectangelporphyre," described by Th. Kjerulf. The well-known rhombic form is entirely absent. Parting parallel to (100) is so distinct that the cleavage pieces are very difficult to get, the crystal easily breaking into pieces along that face, as seen in Figs. 1 and 2. The twinning according to the Carlsbad law is the most common, very rarely the Manebach type is megascopically recognizable. Two other types (albite and pericline) appear faintly between crossed nicols; sometimes they are locally and irregularly distributed in the inner part of the phenocrysts. In some crystals microperthitic and microline structure are visible. Zonal structure is not uncommon, but is not so distinct as in the case of plagioclase. The outer zone usually shows a slightly lower refraction than that of the inner part, but both are lower than balsam. In one instance, plagioclase appears as a nucleus in the alkaline feldspar. Aegirine-augite and greenish-brown glass are comparatively abundant as inclusions; besides these, apatite needles and magnetite grains are usually inclosed

in small amounts. The mean index of refraction of the mineral measured by Wright's is $n_D = 1.526 - 1.531$. The extinction angle on (010) is $+5°$ to $+9°$, and on (001) 0 to $+1°$. The characteristic undulatory extinction is well marked. The plane of the optic axes is approximately perpendicular to (010), and the negative acute bisectrix is nearly normal to $(\bar{2}01)$. The apparent optical angle measured on the section nearly parallel to $(\bar{2}01)$, by Mallard-Becke's method, is $84° 44'$ and 2V is $52° 20'$, the mean index of refraction being assumed as $n_D = 1.528$. The dispersion is $\rho > \nu$.

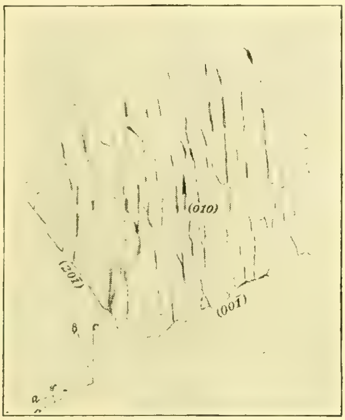

FIG. 1

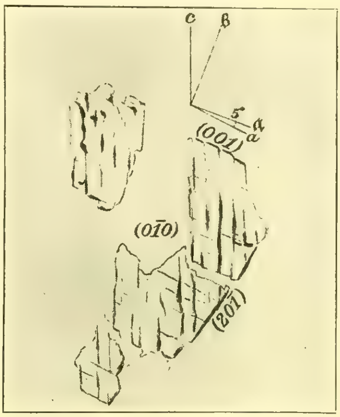

FIG. 2

The groundmass feldspars are also alkaline feldspar and occur in elongated prisms, simple Carlsbad twinning being commonly present. They are arranged as in trachytic fabric and the fluxion is especially marked around the phenocrysts.

Aegirine-augite, as phenocrysts, is almost absent, and the largest crystal, which was observed in 5 thin sections, measures 1.5 mm. in length, but the average length of the prisms is 0.2 mm. The mineral is of bluish-green color, and is somewhat pleochroic from bluish-green to the same color with yellowish tint. The greatest extinction angle measured with respect to the *c* axis, gave 45°. As inclusions magnetic grains are common; and brown glass, appatite needles, and feldspar laths can be detatched, the last being very scarce.

Olivine occurs in some specimens, as a very rare accessory in an anhedral form.

Magnetite is very scarce as phenocrysts. Minute euhedral to anhedral crystals are disseminated in the groundmass, and form about 4 per cent of the whole. It is also associated with the aegirine-augite.

Apatite is conspicuous as very minute needle-shaped crystals.

Chemical characters.—Separate analyses were made of the rock and of the porphyritic anorthoclase.

For the purpose of analysis of the mineral, the phenocrysts were picked out of the weathered rock, in which the minerals remain on the surface in a favorable state to be taken off from the matrix. The feldspar material is quite fresh, but the surface and the inner portions along the parting and cracks are stained by decomposed products from the matrix and inclusions. To purify it as much as possible, it was crushed into 1–2 mm. grains and was digested in dilute hydrochloric acid at 80° C. for 24 hours, until it turned white in appearance. But an intimate association with impurities rendered it impossible to prepare a thoroughly clean sample, so that the results of analysis are somewhat unsatisfactory. The chemical analysis, made by S. Kawamura in the laboratory of the Imperial Geological Survey of Japan, is as follows:

SiO_2	64.98
Al_2O_3	19.62
Fe_2O_3	0.98
MgO	0.22
CaO	3.48
Na_2O	4.86
K_2O	5.83
	99.93

By the withdrawal of the excess of silica, lime, magnesia, and iron as impurities mainly due to inclusions, the chemical composition of the mineral is shown approximately by the following ratios:

SiO_2	63.08
Al_2O_3	21.80
CaO	3.24
Na_2O	5.39
K_2O	6.49
	100.00

From these figures the formula of the anorthoclase is found to be $Or_{2.38}Ab_3An_1$.

The analysis of the rock, by K. Takayanagi, and that of the pantelleritic trachyte, by Förnstner, are given in the following table:

	A	B
SiO_2	62.36	61.43
Al_2O_3	17.95	17.51
Fe_2O_3	1.55	5.11
FeO	2.62	2.30
MgO	0.72	0.54
CaO	2.75	2.45
Na_2O	5.60	6.22
K_2O	4.16	3.95
H_2O*	0.87	....
TiO_2	0.66	....
P_2O_5	0.29	....
MnO	0.48	....
	100.10	99.51

* Loss on ignition.

A = Soda-trachyte, Matsu-shima, Kyûshû.

B = Augite-andesite (pantelleritic trachyte of Rosenbusch), Porto Scauri, Pantelleria.

The norms, calculated from these analyses, are as follows:

	A	B
Quartz	6.1	5.0
Orthoclase	25.0	23.4
Albite	47.2	52.4
Anorthite	11.4	8.1
Diopside	0.7	3.3
Hypersthene	4.6	....
Magnetite	2.3	7.4
Ilmenite	1.4	....
Apatite	0.6	....
	99.3	99.6

Ratios from the norms are given below:

	A	B
$\frac{\text{Sal}}{\text{Fem}}=$	9.25	8.31
$\frac{Q}{F}=$	0.07	0.06
$\frac{K_2O'+Na_2O'}{CaO'}=$	3.29	4.90
$\frac{K_2O'}{Na_2O'}=$	0.50	0.42

In the quantitative system, the rock from Matsu-shima would be classified under the name of laurvikose, near pulaskose. There is a close resemblance in chemical characters between this rock and the pantelleritic trachyte which was described by Förnstner as augite-andesite, and is also laurvikose. The relationship between them is shown in the above tables.

PRELIMINARY NOTES ON SOME IGNEOUS ROCKS OF JAPAN. II[1]

S. KÔZU
Imperial Geological Survey of Japan

II. QUARTZ-BASALT

Locality.—Kasa-yama, near Hagi city, prov. Nagato.

Occurrence.—The rock occurs as a lava flow erupted at the volcano Kasa-yama, which consists merely of an isolated cone of small size, 112.5 meters above the sea-level and about 1,300 meters in diameter across its base. In the summit, there is a perfectly preserved crater, 25 meters in diameter and 13 meters in depth. This small and regular cone stands in strong contrast to the topography of the environs, where the geology is mainly composed of granites and mesozoic sedimentaries, and especially to that of table-lands or flat islands formed by basalt flows which poured out here and there through the ground.

Age.—The eruption of the rock appears to be Diluvium and the latest of the basalt in this region, which seem to have been erupted at the period from the close of Tertiary to Diluvium.

Megascopic characters.—The specimen collected from the lava dam near the Shinto shrine at the eastern foot of Kasa-yama is noteworthy for containing abundant quartz as porphyritic grains in a hypocrystalline groundmass. It is black in color and vesicular with small and irregular cavities, but has a high specific gravity. The quartz, varying in size from 1 mm. to 5 mm., shows an irregular outline, but sometimes almost hexagonal. Though the percentage of quartz grains varies in different portions of the lava, generally they are distributed uniformly and are clearly distinguishable from the groundmass by their color, as seen in the photograph. Besides these there are only a few crystals of yellow

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olivine as megascopic phenocrysts. This mineral is 2 mm. in diameter, and is also fresh in aspect.

Microscopical characters.—The mineral components are olivine, augite, plagioclase, magnetite, and apatite, with phenocrystic quartz. The microscopic phenocrysts are not abundant; among them the olivine is most common, then follows the augite in nearly equal amounts; the plagioclase occurs subordinately. The ground-

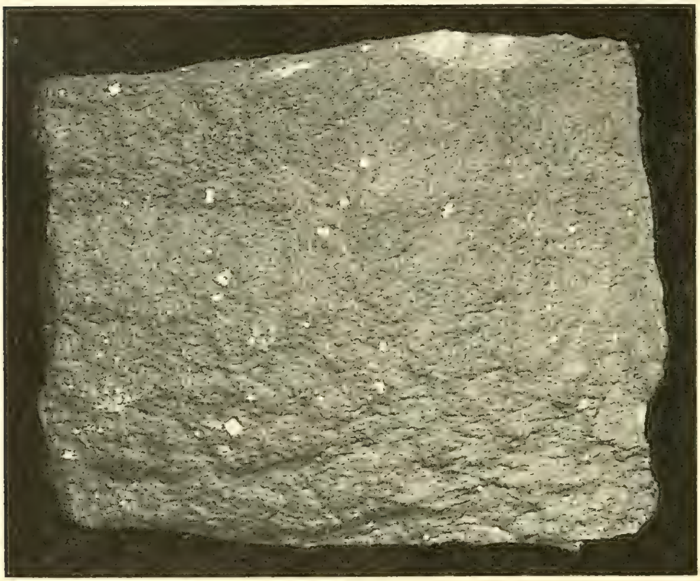

FIG. 1.—Quartz-basalt. $\times\frac{1}{2}$. The white grains are quartz.

mass is hypocrystalline in texture and consists of lath-shaped plagioclase, prismatic or granular augite, and magnetite crystals, with abundant interstitial glass of light-brown color, clouded by numerous globules.

Olivine belongs to the earlier crystallization among the mineral ingredients of the rock, and is almost free from inclusions with the exception of a few crystals of magnetite and glass, which are very rare. It forms anhedral to subhedral shapes with finely ragged outline, and about it minute granules of pyroxene may be observed.

The olivine is entirely fresh and remarkably but irregularly cracked.

Augite is very faint yellowish or nearly colorless, and is more abundant than olivine, though it is rarely present as microscopic phenocrysts. As phenocrysts, it is anhedral, but in the groundmass it is well shaped; elongated prisms are common. In rare instances, twinning parallel to the orthopinacoid may be seen in the larger crystals. In the reaction-border about the phenocrystic quartz, augite is the only mineral constituent and is imbedded in brown glass. Inclusions of magnetite, apatite, and glass are sparingly present.

Plagioclase is basic labradorite and appears in well-formed, long prismoids with polysynthetic twinning according to the Carlsbad and albite law. Zoning is almost absent. Minute grains of pyroxene and magnetite are present as inclusions in small quantity, with also a few of glass.

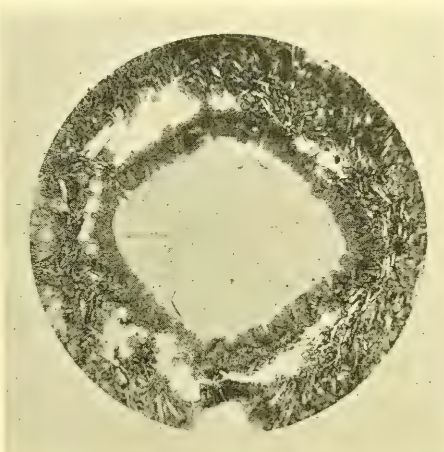

FIG. 2.—Bipyramidal quartz with reaction border. ×23.

Quartz occurs as a porphyritic constituent, and the average diameter is about 2 mm. The outline of the mineral in thin section is usually irregular, but sometimes shows the bipyramidal form referable to crystallographic faces, as seen in the microphotograph (Fig. 2). Each grain of quartz is fringed with a reaction-border, consisting of elongated prism and grains of augite imbedded in brown glass. The minute prismoids are arranged quite regularly. They are grouped radially, each group containing a few crystals that converge toward the outer side of the border, as seen in Fig. 2. In triangular, interstitial spaces between each radial group granular augites are scattered irregularly. In some instances, the deep invasion of the brown glass,

with very fine crystals of augite, is observed along the cracks in the quartz. Glass inclusions with gas bubbles are present in bipyramidal shapes, and ruptures starting from the four corners of the rhombic sections are well marked in thin sections of the mineral nearly parallel to the optic axis, as shown in Figs. 3 and 4.

FIG. 3

FIG. 4

Chemical characters.—The analysis of the rock, shown in column A in the following table, was made by T. Ōno in the laboratory of the Imperial Geological Survey of Japan. The analysis of the quartz-basalt from the north base of Lassen peak, described by Diller, is given in column B.

	A	B
SiO_2	56.08	56.51
Al_2O_3	18.12	18.10
Fe_2O_3	2.46	4.26
FeO	6.97	2.68
MgO	3.13	4.52
CaO	7.14	8.15
Na_2O	2.02	3.23
K_2O	1.50	1.15
H_2O	0.15*	0.69
TiO_2	1.31	0.48
P_2O_5	tr.	0.14
MnO	0.34	0.11
BaO	....	0.04
Cr_2O_3	....	tr.
SrO	....	0.04
LiO	....	tr.
	99.22	100.10

A. Quartz-basalt (lava). Kasa-yama, prov. Nagato.
B. Quartz-basalt (lava). North base of Lassen Peak, California.

* Loss on ignition.

On comparing the analyses, it is obvious that the two rocks are closely similar in chemical characters, but the rock of Kasayama differs slightly in containing lower magnesia, lime, and alkalies, and higher iron and titanium; the low value of the first component especially does not satisfy Harker's hypothesis with regard to the plotting of his diagram.

Norms, calculated from the analyses, are as follows:

	A	B
Quartz	14.8	10.9
Orthoclase	8.9	7.2
Albite	16.8	26.7
Anorthite	35.3	31.4
Corundum	0.2	....
Diopside	....	7.1
Hypersthene	16.9	8.6
Magnetite	3.7	6.3
Ilmenite	2.4	0.9
	99.0	99.1

From the norms, ratios are given as below:

	A	B
$\frac{Sal}{Fem}=$	3.30	3.33
$\frac{Q}{F}=$	0.24	0.17
$\frac{K_2O'+Na_2O'}{CaO'}=$	0.38	0.57
$\frac{K_2O'}{Na_2O'}=$	0.50	0.25

By the Quantitative System these rocks are classified as bandose.

PRELIMINARY NOTES ON SOME IGNEOUS ROCKS OF JAPAN. III[1]

S. KÔZU
Imperial Geological Survey of Japan

III. ALKALI-FELDSPAR-BEARING BASALTIC ROCK (FUKAE-GAN) AND ALKALI-FELDSPAR-BEARING BASALT

Localities.—Alkali-feldspar-bearing basaltic rocks were collected from Fukae-shima in the Gotō Islands; alkali-feldspar-bearing basalts from Madara-shima, an islet northwest of the Yobuko port, prov. Hizen; from Ō-shima, near the Island of Iki; from Uramino-taki, near Omura city, prov. Hizen. These localities are in the northern part of Kyûshû or its outlying islands.

Occurrence.—The rock type, associated with olivine-basalt on the one hand and with soda-trachyte[2] on the other, appears to have an extended distribution over the northern part of Kyûshû. At Fukae-shima, this rock group forms the plateau and some striking dome-shaped hills standing on it, as seen in the photographs (Figs. 1 and 2). There are well preserved or strongly breached craters in the summit of each dome. The hills, in great part, consist of ashes, lapilli, and slaggy lava, in which finely shaped bombs may be found abundantly. The plateau is of hard lava.

Age.—Near the close of Tertiary to Diluvium.

The specimens for the following descriptions were collected by the writer from Fukae-shima; by Y. Ōtsuki from Madara-shima and Ō-shima; and by D. Satô from Uramino-taki. They may be classified in two groups by the mineralogical and chemical characters.

I. *Alkali-feldspar-bearing basaltic rock* (*Fukae-gan in Japanese*).—The rocks of this group collected from Fukae-shima are transi-

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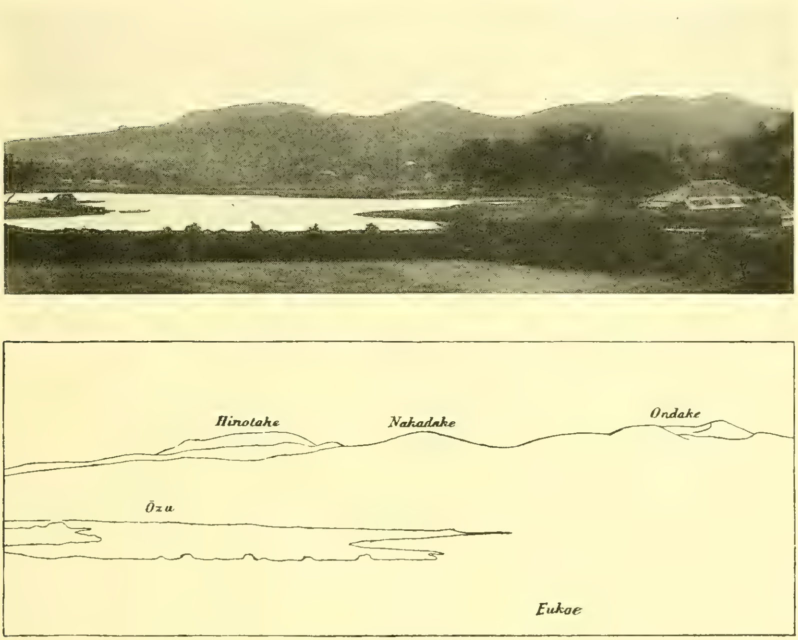
[2] *Jour. Geol.*, XIX (1911).

tional forms in both texture and mineralogical characters, owing to their crystallinity, but are closely alike in chemical properties. They are represented by three types as described below.

As the first type, a bomb ejected from the volcano Ondake was selected for the following description and chemical analysis:



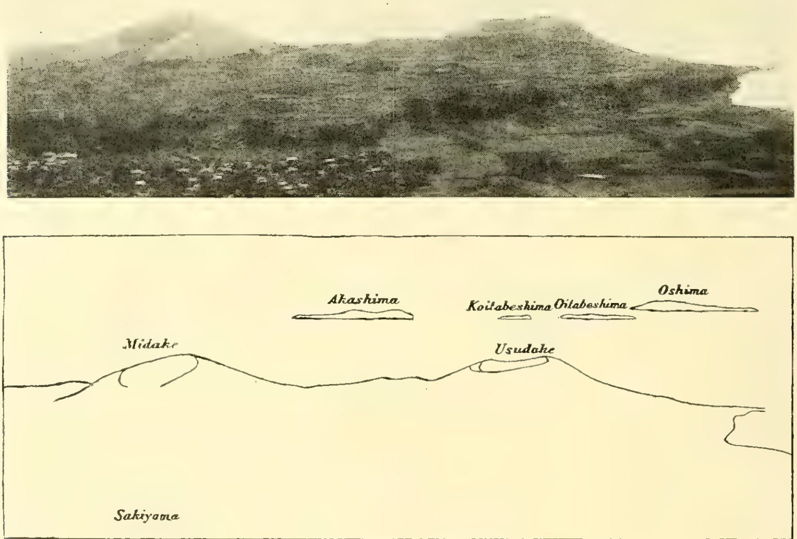
View from the northwest

FIG. 1

Megascopic characters.—This rock type is aphanitic and black in color. Scattered magnophyric feldspars are the only constituents visible to the naked eye. The groundmass is vesicular, and the vesicles are small and round. The phenocrysts are of fresh aspect and show rather euhedral forms, short prismatic or tabular, and in some instances are of considerable size, reaching 20 mm. in length (Fig. 3). Olivine, which is present as abundant microscopical phenocrysts, is scarcely recognizable even by the aid of a lens.

Microscopical characters.—The microscopic phenocrysts in this type of rock are of olivine in great part, with subordinate andesine. The groundmass is hypocrystalline and is filled with small and round vesicles (Fig. 4), looking like the outline of leucite.

Feldspar.—This mineral shows distinctly two different habits. The phenocrysts are stout prismoid, sometimes tabular, and some-



View from the north west

FIG. 2

what rounded. They are andesine (Ab_3An_2), with a mean index of refraction slightly higher than $n_y = 1.554$. They contain abundant small particles forming an outer zone, and round it usually, thin and clean layers with different composition, but the difference between each layer is not pronounced. Twinning is scarce, and in rare instances undulatory extinction can be observed. Feldspars forming the groundmass are slightly more sodic than the phenocrysts, and occur in elongated or rather slender shapes. They are

marked by irregular cracks, filled with isotropic, low refractive, and colorless, substance. Twinning according to the albite law is common.

Olivine occurs in two-sized crystals. The larger ones are abundant and play an important rôle as microscopic phenocrysts. Their shapes are equant or prismoid. In many instances, the outlines of crystals are irregular by invasion of groundmass, sometimes

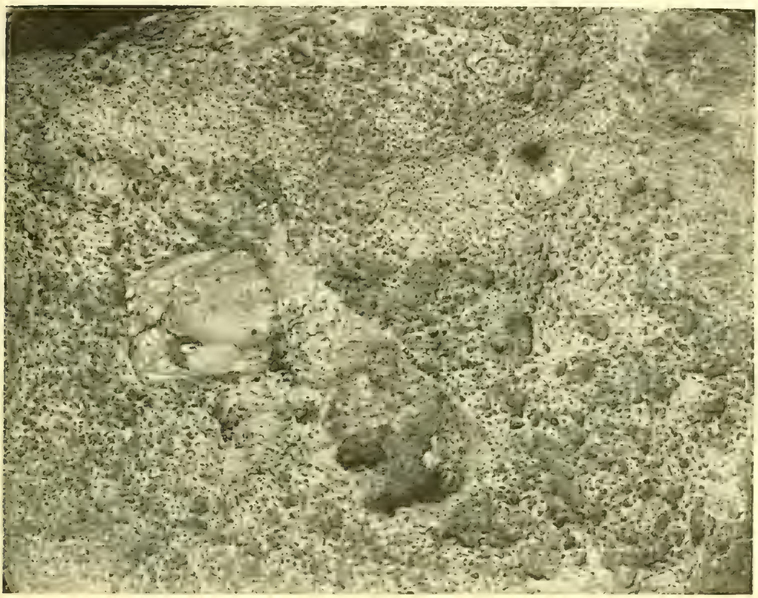


FIG. 3.—Andesine phenocryst, natural size

extremely narrow and deep, parallel to crystallographic faces, showing the successive growth of the mineral, but the general outlines are referable to crystal forms (Figs. 5 and 6). Though distinctly cracked they are entirely fresh and inclose clouded glass, but are free from other inclusions.

Augite forms magnophyric crystals which are very rarely seen in hand specimens. The minute grains in the base, showing high refraction, appear to be augite.

Magnetite clouds the base as minute grains or dusty particles, and their abundant presence affects the color of the rock. *Apatite* appears mostly as inclusions in feldspar.

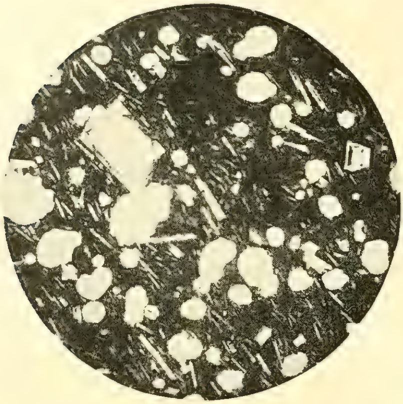


FIG. 4.—Microphotograph of the first type of the first group, magnified 30 times. The minerals seen in the figure are olivine microphenocrysts and andesine prisms.

The second type collected from Ōhama in Fukae-shima is more crystalline. Alkali-feldspar appears locally in the crystalline part as the border of the plagioclase of the groundmass. The augite crystals are comparatively few and occur in small anhedral forms. The magnetite crystals are more numerous in this type of rock than in the first one, are somewhat larger, but are also anhedral in shape (Fig. 7).

The third type collected from Masuda in Fukae-shima is holocrystalline, and in some parts has typical ophitic texture. The mineral components are andesine, alkali-feldspar, augite, olivine, magnetite, and apatite. The andesine is distinctly cracked, with

FIG. 5

FIG. 6

FIGS. 5 AND 6.—Showing irregularly outlined olivines. ×55

invasion of colorless, low refractive and isotropic substance as in the above types. The alkali-feldspar occurs as the border of almost all crystals of andesine in the groundmass. The augite is light purple in color, and is xenomorphic toward plagioclase. The magnetite frequently occurs in crystal form.

II. *Alkali-feldspar-bearing basalt.*—

This group differs from the above in the presence of labradorite in the place of andesine, as the essential component.

The specimen from Madara-shima is dark reddish gray in color with semiwaxy luster. It is holocrystalline, fine granular, and

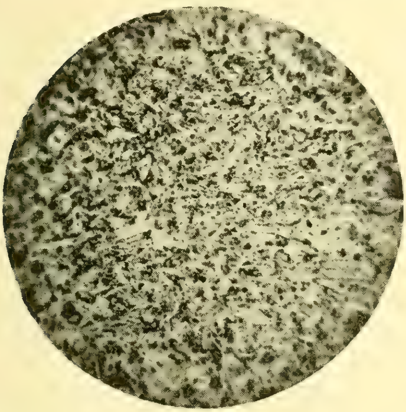


FIG. 7.—Microphotograph of the second type of the first group. ×30.

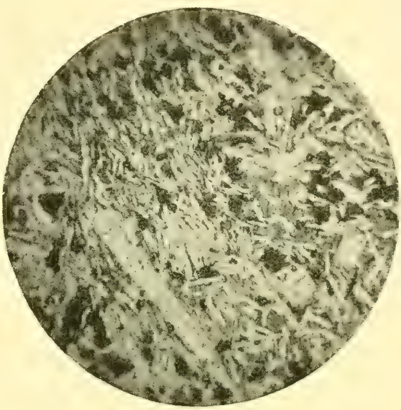


FIG. 8.—Microphotograph of the third type of the first group. ×30.

inconspicuously porphyritic, with not abundant magniphyric feldspar and less pyroxene.

Under the microscope the rock consists of labradorite, alkali-feldspar, augite, olivine, titaniferous iron ores, and apatite. The labradorite is subhedral to euhedral, twinned according to the Carlsbad and albite laws, and commonly prismatic in shape. Zonal structure is rarely seen. Each of the feldspar crystals composing the groundmass is enveloped by a shell of alkali-feldspar. The augite is light greenish yellow with purple tinge, and is subhedral to anhedral, stout prismatic to equant. The larger ones are indistinct phenocrysts; the minute grains are interstitially distributed in the groundmass with magnetite crystals. The olivine

as microscopic phenocrysts is subhedral to anhedral, and alteration into iddingsite is commonly visible along cracks and in marginal portions. The texture of the groundmass is somewhat intersertal, and is characterized by divergent arrangement of prisms of plagioclase enveloped by alkali-feldspar, with interstitial granules of augite, olivine, and magnetite (Fig. 9).

A more distinctly crystalline and coarser type is a specimen from Ō-shima, an islet, near the Island of Iki.

Megascopically the rock, more or less decomposed, is evidently holocrystalline, but the individual crystals are scarcely recognizable, though the diverse arrangement of prismoid feldspars, 1.5 to 2 mm. long, is well marked in the hand specimen. The color is light gray, on account of the abundant feldspars, and is dotted by dull reddish brown spots produced by decomposition of the olivine. Rare, inconspicuous phenocrysts are tabular, white feldspar; irregularly shaped black augite; and equant, dark reddish olivine. All of them are less than 3 mm. in diameter.

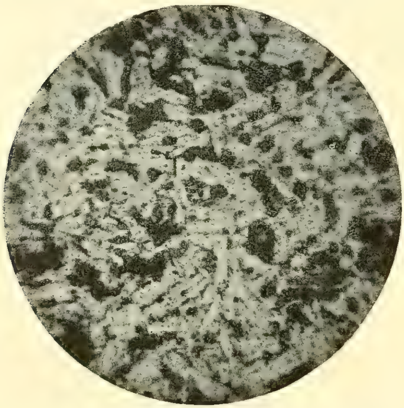


FIG. 9.—Microphotograph of the alkali-feldspar-bearing basalt from Madara-shima. ×30.

Under the microscope (Fig. 10), the texture is transitional from doleritic to intersertal, as the augite is xenomorphic toward feldspar in one case and automorphic in the other. The mineralogical constituents are as before, but the presence of broad bands of alkali-feldspar enveloping labradorite is especially noticeable (Fig. 11). In some crystals, the alkali-feldspar has more than three times the volume of the labradorite, that is, 0.75 mm. in length and 0.09 mm. in width (Fig. 11). In general, the labradorite is in extremely elongated prisms, twinned according to the Carlsbad and albite laws. The augite is anhedral to subhedral, prismatic to equant. In color it is light purple. The magnetite frequently occurs in

anhedrons 0.35 mm. in diameter. The apatite is noticeable in elongated prisms.

The most finely grained variety is from Uramino-taki. It is light gray, compact with a few vesicles, and nonporphyritic, sometimes with nodular olivine. There are groups of scaly, blackish brown mica in the vesicles.

Under the microscope it is almost holocrystalline and granular. The mineralogical components are the same as in the previous variety, with a small quantity of biotite, which usually occurs in cavities. The biotite is reddish brown and strongly pleochroic. Its apparent optical angle ($2E$) varies between 37.5° and 29.5°.

FIG. 10

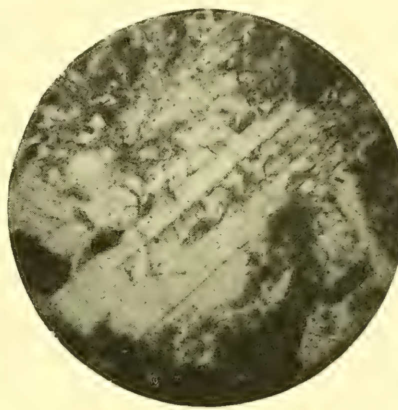


FIG. 11

Chemical characters.—Of the first group of rocks a complete analysis was made of the first type (Bomb) and two partial analyses of the second (B) and third (C) types, by K. Yokoyama. Of the rocks of the second group a complete analysis of a specimen (D) collected from Marada-shima was made by T. Ōno.

The three analyses A, B, and C of the first group show a close relationship in chemical characters, notwithstanding they have different mineralogical components due to their crystallinity. Foreign rocks that have a close resemblance in chemical characters with the rocks of this group are olivine basalt (E) and orthoclase-bearing doleritic basalt (F) of New South Wales, described by

G. W. Card. For the sake of comparison, these analyses are given in the following table with those of the rocks under consideration.

	A	B	C	D	E	F	G
SiO_2	48.33	49.15	48.70	52.19	48.98	53.21	49.24
Al_2O_3	16.29	....	....	19.74	16.88	17.84	15.84
Fe_2O_3	3.24	....	....	4.72	3.30	3.80	6.09
FeO	8.73	....	....	6.28	7.29	5.22	7.18
MgO	5.70	....	....	2.24	5.27	2.96	3.02
CaO	8.50	....	....	6.99	8.86	6.48	5.26
Na_2O	3.59	3.64	3.35	3.48	3.39	3.36	5.21
K_2O	1.49	1.61	1.42	2.04	2.11	3.03	2.10
H_2O+	0.82	....	....	1.25	0.52	0.65	1.08
H_2O-					1.78	1.27	1.61
CO_2	n.d.	....	....	n.d.	0.06	0.02	n.d.
TiO_2	2.40	....	....	n.d.	1.28	1.01	1.84
P_2O_5	0.79	....	....	n.d.	0.30	0.44	1.47
SO_3	n.d.	....	....	n.d.	none	0.09	n.d.
Cl	n.d.	....	....	n.d.	0.02	0.11	n.d.
MnO	0.11	....	....	n.d.	0.31	0.32	0.29
etc.	....	....	....	0.06	0.06	....	0.21
Total	99.99	....	....	99.99	100.41	99.88	100.46
Sp.G.	2.562	....	....	....	2.869	2.768	2.79

A. Bomb ejected from the volcano Ondake, Fukae, the Gotō Islands, Analyst, K. Yokoyama.

B. Lava erupted from the volcano Ondake, Ōhama, Fukae, the Gotō Islands, Analyst, K. Yokoyama.

C. Lava erupted from the volcano Ondake, Masuda, Fukae, the Gotō Islands, Analyst, K. Yokoyama.

D. Lava, Madara-shima, prov. Hizen, Analyst, T. Ōno.

E. Olivine-basalt, one and a half miles north of St. George's head, N.S.W.

F. Orthoclase-bearing doleritic basalt, south side of Croobyar Creek, N.S.W.

G. Mugearite, Druim na Criche, 5 miles S.S.W. of Portree, Skye.

The norms calculated from these analyses are as follows:

	A	D	E	F	G
Quartz	....	3.2	....	4.9	....
Orthoclase	8.9	11.7	12.2	17.8	12.2
Albite	30.4	29.3	28.8	26.7	44.0
Anorthite	23.9	32.3	24.7	24.5	13.6
Sodium chloride	....	....	....	0.4	....
Diopside	11.0	2.1	14.6	3.9	3.4
Hypersthene	2.7	12.2	....	10.8	1.1
Olivine	11.5	....	9.7	....	7.6
Magnetite	4.6	6.7	4.9	5.6	8.8
Ilmenite	4.6	....	2.4	2.0	3.5
Apatite	1.9	....	0.7	1.3	3.1
	99.5	97.5	98.0	97.9	97.3

Ratios calculated from the norms are as follows:

	A	D	E	F	G
$\frac{Sal}{Fem}$	1.74	3.64	2.03	3.16	2.51
$\frac{Q+L}{F}$	....	0.04	....	0.009	....
$\frac{K_2O'+Na_2O'}{CaO'}$	0.86	0.66	0.87	0.99	2.16
$\frac{K_2O'}{Na_2O'}$	0.28	0.38	0.40	0.59	0.26

By the quantitative system, A, D, E, and F would be classified under the name andose and G under akerose.

From the tables given above, it is clear that the rocks from Fukae differ from normal basalt, in containing a high percentage of alkalies in proportion to the silica contents, especially of soda, forming normative andesine $Ab_{58}An_{42}$, which is slightly more calcic than the modal plagioclase. Though the alkali-feldspar is not present as a recognizable mineral in the first type (Bomb) of the first rock group, its molecule is to be looked for in the glass-base. In the second and third type, the alakli-feldspar is seen in the modal state. The chemical resemblance between the rock of Fukae, A, and the olivine-basalt from St. George's Head, E, is very close. The differences between them are lower potash for orthoclase, slightly higher soda for plagioclase and higher normative ilmenite in the Fukae rocks, compared with the olivine-basalt, of St. George's Head. Generally the rock is characterized by properties mineralogically and chemically intermediate between the mugearite, G, described by Harker, and the olivine-basalt described by Card, though it is very near to the last rock, and it differs from shoshonite described by Iddings in being dosodic.

The rock from Madara-shima, D, differs slightly from the Fukae rock in the lower value of magnesia and in higher percentages of silica and potash, and of alumina which increases the normative anorthite. It has a close resemblance in chemical characters to the orthoclase-bearing doleritic basalt, F, from Croobyar Creek, New South Wales, described by Card.

Reviews

Gypsum Deposits of New York. By D. H. NEWLAND AND HENRY LEIGHTON. New York State Museum Bulletin 143, Albany, 1910. Pp. 94.

The bulletin presents a concise but complete description of the gypsum deposits and the gypsum industry of the state of New York. The workable deposits are restricted to the Salina state of the upper Silurian and are pretty generally confined to a single formation of this series, the Camillus shale. The geology of the Salina series is carefully and clearly set forth.

Considerable attention is given to general questions relating to the origin of gypsum, its properties, and the theory of its transformation into plasters. The reviewer is pleased to note that the section devoted to the description of mines and quarries is much shorter than is usually found in a report of this character.

E. R. L.

Report on a Part of the Northwest Territories Drained by the Winisk and Attawapiskat Rivers. By WILLIAM McINNES. *Geol. Survey of Canada,* No. 1008. Pp. 54; Figs. 5; Map 1.

In this report the author gives the results of a reconnaissance survey of the country to the southwest of Hudson Bay. Adjacent to the bay there are gently folded Silurian limestones and dolomites, probably of Niagaran age. Outside this belt comes a belt of bowlder clay 160 miles in width, overlain by post-glacial marine clays, which, below the Boskineig fall in the Winisk River, have an altitude of 350 feet above sea-level. Beyond this again is the Laurentian peneplain, of Archean granites and schists. This is the customary rocky-lake country, heavily drift covered in places. Glacial striae on exposed rock surfaces indicate a glacial movement toward the S.S.W.

The writer also gives a general description of the canoe routes, flora and fauna of the country, climate and possibilities of agriculture.

H. C. C.

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THE IOWAN DRIFT

SAMUEL CALVIN

CONTENTS

INTRODUCTION

Is there an Iowan drift? Whatever the reader may think about it, the question seems to be in order. Three papers have recently appeared in which the Iowan drift receives more or less attention.[1] Two of the papers go so far as to question the very existence of such a sheet of drift as that which geologists have for

[1] Frank Leverett, "Weathering and Erosion as Time Measures," *American Journal of Science*, XXVII, May, 1909.

———, "Comparison of North American and European Glacial Deposits," *Zeitschrift für Gletscherkunde*, IV, Berlin, 1910.

T. C. Chamberlin, "'Comparison of North American and European Glacial Deposits,' by Frank Leverett;" a review of the second paper, *Journal of Geology*, XVIII, No. 5, July-August, 1910.

some time been calling Iowan. The third paper raises the question whether, even if there is such a drift, the name it has been wearing should not be applied to something else. It is possible that the questions raised by these papers may never be settled to the satisfaction of everyone, because men do not always see alike; but a few facts bearing on the subject may be worthy of consideration.

CAUSE OF CONFUSION IN USE OF THE TERMS KANSAN AND IOWAN

The doubt as to the correct use of the terms Kansan and Iowan is the one that deserves first and most serious attention. This doubt has arisen naturally and for admittedly good reasons, but it is all due to the fact that in the earlier discussions of the Pleistocene deposits of northeastern Iowa it was assumed that there were but two drift sheets east of the Wisconsin lobe which occupies the north-central part of the state. The two supposed drifts were named by McGee[1] the Upper and the Lower till. The view that there are but two tills in this area was adopted by Chamberlin in his classic contribution to the third edition of *The Great Ice Age*, by James Geikie,[2] and the name East-Iowan was given to what was assumed to be McGee's Upper till, while what was taken to be the Lower till was called Kansan. There are, however, three drift sheets in the region, and the attempts to describe three formations in terms of two led to confusion. In some cases the upper and middle sheets were described as a unit; in others the lower and middle were treated as one; much more frequently the lowest was ignored, and the descriptions of the "lower" and "upper" tills were drawn from the other two. The presence in certain localities of a forest bed or interglacial gravels, which it was assumed always lay between what the authors described as upper and lower tills, as East-Iowan and Kansan, complicated matters still further. There are, indeed, many positive references in the original texts to this forest and gravel horizon—since called Aftonian—as the plane of separation between the two drift sheets

[1] Paper on "The Pleistocene History of Northeastern Iowa," by W J McGee, *Eleventh Annual Report of the United States Geological Survey*, Part I, 1891, pp. 189–577; and other papers by the same author.

[2] *The Great Ice Age*, 3d ed., chaps. xli and xlii, "Glacial Phenomena of North America," by Professor T. C. Chamberlin, pp. 724–74, 1895.

at that time credited to the region; but if the texts relating to the subject are carefully read and the maps published in connection with them are examined, it will be seen that the view that the lower till, the Kansan, lies below the Aftonian is untenable. For example, the description of the materials and prevailing color of the upper till on p. 476 of the *Eleventh Annual Report* is true for only the third of the drift sheets and is at variance with the facts if intended to include the middle till. The same is true of the reference to the large granite bowlders as "the most conspicuous element of the upper till," on p. 481. On the other hand, the characteristics assigned to the lower till in the comparisons made between it and the upper on p. 479, are all features that belong to the middle drift sheet; in no true sense are they descriptive of the sub-Aftonian. It is true that at the end of the paragraph there is a reference to the "forest bed" as a plane of separation between the upper and lower tills, but the characters which the author saw and so correctly and graphically described belong to a super-Aftonian till and to nothing else.

If now we turn to the chapters on "Glacial Phenomena of North America," contributed by Professor Chamberlin to Geikie's *Great Ice Age*, we shall see again how the preconception that there were but two drifts where three actually exist, led unavoidably to confusion. It is no reflection on anyone that such confusion crept in in the earlier discussions. Some things are unavoidably overlooked by the pioneer who opens up for us new fields of science, and we can but admire the genius and the insight of the masters who taught us how to read the complicated history of the Pleistocene deposits of the Mississippi Valley. As in the *Eleventh Annual Report*, so in the *Great Ice Age*, it is two super-Aftonian tills that are most frequently referred to in the text, and most accurately represented on the map opposite p. 727 as, East-Iowan and Kansan. The distinguishing characteristics of the upper and middle drift sheets could not be more clearly or more succinctly stated than is done on p. 760 of the work cited where, speaking of the East-Iowan, it is said:

In Iowa the granitic types predominate. Immense bowlders are freely scattered over a portion of the surface. As greenstones prevail in the lower

till, there is a petrological as well as a stratigraphical basis for separating the two formations. . . . .

The most notable feature of this drift sheet is its connection with the main deposits of loess. . . . . The East-Iowan till sheet is, however, associated with loess of such exceptional extent and nature as to make this epoch especially notable on account of this relationship. As already stated, the till graduates at its edge into loess that spreads away from its border.

The statements quoted can be interpreted in but one way. They are true in case the term East-Iowan was applied to the uppermost of the three till sheets in Iowa east of the Wisconsin moraine. There is just one till in which "granitic types predominate." There is just one of which it can be said that "immense bowlders are freely scattered over a portion of the surface." There is just one that bears the described relation to the loess. While greenstones occur in all three of the till sheets of the area under consideration, it is in the middle sheet that they are most conspicuously prevalent.

The statement on p. 756 of *The Great Ice Age*, clearly implied if indirectly made, that "the Kansan formation emerges from beneath the overlapping East-Iowan formation to the extent of 200 miles at the west" can apply only to a sub-Iowan, but super-Aftonian drift. It cannot possibly apply to the sub-Aftonian for the reason that at the time it was written the known natural exposures of the sub-Aftonian were confined to a very limited area. A number of outcrops of this formation have since been recognized and recorded, but it may be questioned whether the aggregate of all the now known exposures of sub-Aftonian would be equal to more than one or two square miles. Certainly there are no known areas of anything approaching 200 miles in extent in which the lowest of our drift sheets emerges from beneath anything so as to justify its representation on a map. Other statements that can apply only to what geologists have recently and consistently been calling Kansan occur on p. 757. The Kansan, we are told, "is greatly worn in regions where the denuding agents have worked under favorable conditions. . . . . In other regions of flat surface and low declivity the degradation is less marked, and extensive remnants of the original surface-plane have been preserved." The first super-Aftonian drift fulfils the conditions of the parts of the text quoted and of many others; the sub-Aftonian does not.

While admitting, then, all that may be claimed for the frequent references to the Aftonian soils, forests, peats, and gravels, it must also be admitted that the descriptions in the early texts, which treat of the texture, color, and petrological contents of the Kansan and the Iowan, are based on observations made on two super-Aftonian drifts. If there could remain a particle of doubt on this point after reading the texts, the doubt would be dispelled by an examination of the map opposite p. 727 of *The Great Ice Age*. The drifts of the two areas represented as Kansan and Iowan respectively are both super-Aftonian, and, considering the state of knowledge at the time, the map is remarkably correct. The eastern edge of the Iowan could scarcely be better drawn today. With the exception of a few points which would be mere microscopic dots on a map of this scale, the whole area mapped as Kansan is covered with super-Aftonian till. There is not a single known natural outcrop of sub-Aftonian in the Kansan area east of the Iowan margin. There are no known outcrops of sub-Aftonian in Illinois, Missouri, or northeastern Kansas where the map shows extensive areas of Kansan. It is only very recently that the presence of sub-Aftonian has been demonstrated in Nebraska; but even here it occurs in vertical sections at the base of bluffs, in such position that it could not well be represented on maps of moderate size. In Nebraska, as in practically all the rest of the area mapped as Kansan, it is a super-Aftonian drift that occupies the Kansan area on the map. In all the earlier texts and maps it is a super-Aftonian drift to which the name Kansan was most persistently and most consistently applied.

EFFECTS ON TEXTS AND MAPS OF MAKING CERTAIN PROPOSED CHANGES IN THE USE OF THE TERMS KANSAN AND IOWAN

As has been said, the imperfection of knowledge at the time the Iowan and Kansan drifts were named led to confusion and inconsistencies of statements, and these are of such character and extent as to make it now utterly impossible to apply the proposed names in any conceivable way that will be in full accord with all the statements of the texts. The frequent and positive references to the horizon of the gravels and forest beds must be admitted and must be given full weight in determining the particular drift sheets to

which the names Kansan and Iowan should be applied. On the other hand, the original descriptions of the lower and upper till—of the Kansan and the Iowan—must have careful consideration, and the evidence of the map in *The Great Ice Age*, above cited, must be taken into account. The descriptions would have to be rewritten and the map redrawn to make them consistent with the view that the Kansan is sub-Aftonian. If the term Kansan is transferred to the sub-Aftonian, and the term Iowan to the drift next above,[1] practically the whole area represented on the map as Kansan would have to be changed to Iowan. The Iowan would then extend into southern Illinois, would cover southern and western Iowa, northern Missouri, eastern Nebraska, and northeastern Kansas. With the transfer of the term to the sub-Aftonian the Kansan would be represented on the map by a few dots and thin lines that could be seen only with the magnifier, the whole area comprising an aggregate of only a few sections; and in the present state of knowledge we could not be certain that Kansas has a cubic foot of Kansan (sub-Aftonian) drift. We are face to face with the fact that any application of the terms Kansan and Iowan involves some inconsistencies, is at variance with some of the statements in the original publications; and so long as we seem to need the terms and have to use them, it is only a question of how to use and apply them so as to do least violence to the original maps and descriptions. If the map and descriptive texts referred to may be taken as representing the intent of the authors, the practice of applying the terms which has been followed, and which seems now to come in for a certain amount of mild condemnation, is the only one that is reasonably consistent or possible. For it must be admitted that if the sub-Aftonian is to be called Kansan, and the first super-Aftonian drift is to be the Iowan, more than nine-tenths of the original descriptions are wholly erroneous and misleading, and the map in *The Great Ice Age* showing the distribution of these drifts is altogether meaningless and at variance with the facts. Recent usage in the application of the terms Kansan and Iowan is based on what seemed to be, and still seems to be, the only reason-

[1] Some such shift as this seems to be favored by what is said in the *Journal of Geology*, July-August, 1910, pp. 473–74.

able interpretation of what the authors had in mind when describing the physical characteristics of the two drift sheets and mapping their areal distribution. A departure from this usage, which would make the sub-Aftonian till Kansan and would apply the term Iowan to the old, weathered till above the Aftonian, with its blue color, its strikingly conspicuous array of greenstones, and with relations to the loess so entirely different from the relations correctly described in the text as pertaining to the Iowan, would necessitate the making of radical and revolutionary changes in the map and descriptive texts above noted. It surely accords better with what was published at the time the names were applied to let recent usage remain unchallenged and unchanged.

EVIDENCE CONCERNING THE IOWAN DRIFT AND ITS GEOLOGICAL RELATIONS

The surprising attitude toward the Iowan drift, expressed in the papers by Leverett, is something difficult to understand. A very little field study in the right places will demonstrate:

1. The Iowan drift is.
2. The Iowan drift is young as compared with the Kansan.
3. The Iowan drift is not a phase of the Kansan.
4. The Iowan drift has very intimate relations to certain bodies of loess.
5. The Iowan drift is not related to the Illinoian.

The Iowan Drift Is

To discuss the question of whether there is an Iowan drift distinct from the super-Aftonian till that has been called Kansan is like undertaking a task that one knows is absolutely useless and unnecessary. For, while the Iowan is thin, and in places is absent, there is here a very substantial drift sheet overlying the Kansan and possessing distinctive characters of its own. The Iowan is separated from the Kansan by a ferretto zone in some places and by weathered gravels in others, while its characteristic topography and remarkable bowlders proclaim its presence throughout extensive areas where no sections are available. Buchanan gravels, distributed by volumes of water from the melting Kansan glaciers,

and disposed in numerous sheets and ridges, were laid down throughout northeastern Iowa, on top of the Kansan till, over the area which, but a short time previously, had been abandoned by the retreating ice. They are true outwash gravels. Exposure during the long interval between the Kansan and the Iowan has wrought profound changes in the decomposable granites and other

Fig. 1.—View in the old gravel pit near Doris, Buchanan County, Iowa, showing Buchanan gravels, a deposit contemporaneous with the closing phase of the Kansan, overlain by the younger Iowan drift.

constituents of the Buchanan deposits; and now these gravel deposits become unimpeachable witnesses to the fact that glaciers belonging to a stage long subsequent to the Kansan distributed a new sheet of till differing from the Kansan in composition, color, and petrological contents. The Iowan is yellow; the Kansan, while normally blue, sometimes weathers yellow; where yellow Iowan rests directly on yellow weathered Kansan, the line of contact may not be as distinct and satisfactory as some observers

might wish; but where the Buchanan gravels intervene, the fact that there is a drift younger than the Kansan and perfectly distinct from it is as clearly indicated as that there are two drifts separated by the Aftonian horizon.

Leaving out, therefore, all the evidence from the multitudes of well sections and all other natural or artificial exposures that do not show the intervening aqueous deposits, a few of the scores of points where a young till overlies super-Kansan gravels may be

FIG. 2.—View in the same pit a few rods west of point shown in Fig. 1, taken while work of excavation was in progress, showing the uneven line of contact between the old gravels and the younger, overlying Iowan. The irregularity in the contact line may be due to plowing or gouging by the Iowan ice.

cited. The best-known of these is the old Illinois Central gravel pit near Doris in Buchanan County, a point that has been frequently mentioned. Here are gravel beds with a maximum thickness of fifteen feet or more. The deposit furnished many hundreds of carloads of railway ballast annually for a number of years. In the central part of the pit the gravel was taken out down to the blue Kansan till, and balls of the same blue till are included in the deposit. At the east end of the excavation there are at least ten feet of yellow till above the gravel, recording a later, newer stage of glaciation. The thickness of the later deposit is variable, for it

was laid down on an uneven surface; but at the point illustrated in Fig. 1, the section of the till, including the black loam at the top, is about eight feet. That the later and newer till is unconformable on the gravel is shown in Fig. 2. The typical bowlders of the Iowan drift belong to this overlying till; there is nothing corresponding to them in the blue Kansan. In the process of excavation a number of the Iowan bowlders were undermined and allowed to fall into the pit. One such, perched on the brink of the excavation, is shown in Fig. 3, and a larger-sized companion, completely undermined, has fallen in. The typical, young, uneroded, bowlder-dotted surface of the younger drift, which stretches away from the margin of the old working, is illustrated in Fig. 4.

A quotation or two from the report on Buchanan County, *Iowa Geological Survey*, VIII, may be pertinent. On pp. 239–40 we read:

A very common relation of Pleistocene deposits is illustrated in the well section on the land of J. W. Welch in the southwest quarter of Section 28, Buffalo Township. The record shows:

	Feet
3. Dark soil and yellow till	4
2. Reddish, ferruginous sand and gravel	23
1. Blue clay, penetrated	1

No. 3 of this section is Iowan drift, No. 2 is Buchanan gravel, and No. 1 is Kansan till.[1] In the same quarter section another well shows,

	Feet
3. Soil and yellow till	22
2. Reddish gravel	11
1. Blue clay, with pockets of sand	19

Although the thickness varies considerably, the members of this last section are severally the same as the corresponding numbers of the one above.

In another part of the same report, p. 209, it is recorded that "the eastern part of Fairbank Township is a very level, dry plateau in which a sheet of Iowan drift varying from two or three to thirty feet in thickness overlies an extensive bed of Buchanan gravels. The plateau is a unique piece of prairie land, without the usual undulations, and without any indications of imperfect drainage. The underlying gravel seems to afford an easy means of escape for the surplus surface waters."

[1] Owing to an error in proofreading the terms Iowan and Kansan are transposed on p. 240 of the volume cited.

Many similar cases could be cited, but it surely is not necessary to multiply arguments in support of a fact that is so perfectly obvious as the existence of the Iowan drift (Figs. 1 and 2). There is no sheet of till that has more distinctive characters, more definite stratigraphic relations. A glacial deposit showing thicknesses of 4 feet, 10 feet, 22 feet, 30 feet, a deposit with distinctive bowlders of enormous size, a deposit that is young, fresh, uneroded, and separated from the Kansan by a weathered ferretto zone and profoundly altered gravels, is certainly a very real and substantial

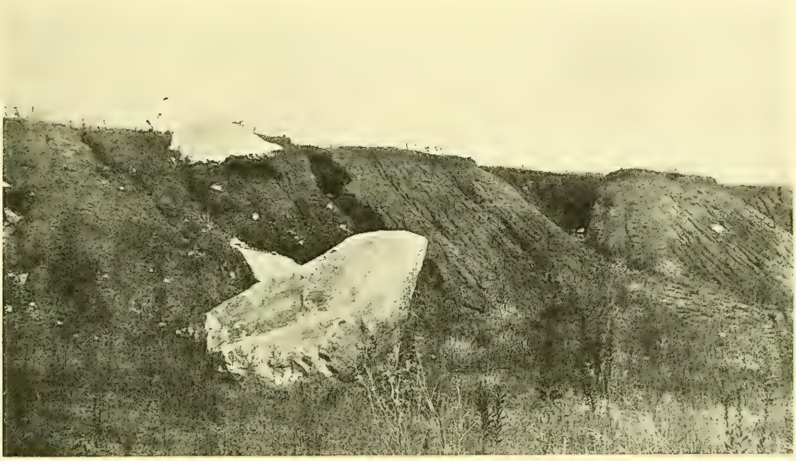

Fig. 3.—View in the Doris gravel pit, showing undermined Iowan bowlders; one is still perched on the brink of the excavation; the larger companion has fallen into the pit.

thing that may not be disposed of by referring to it as "only the weathered surface of a drift," or by the use of such a qualifying phrase as "so-called Iowan."

That there are two gravel horizons in this region—one Aftonian, the other Buchanan, one below the blue Kansan drift, the other above it—is indicated by two wells near the northwest corner of Section 22, Buffalo Township, Buchanan County. One of the wells, 152 feet deep and ending in gravel (Aftonian) which lies beneath the Kansan, furnishes a constant stream of water an inch in diameter; the other, which is not flowing, is 25 feet deep and ends in a bed of Buchanan gravel which overlies Kansan.

From the other counties included in the Iowan area comes evidence of the distinctive character of the Iowan drift similar to the evidence from Buchanan. Probably the banner county in Iowa for inter-Kansan-Iowan gravels is Floyd. Here are scores of exposures, occupying every conceivable position from the flood plains of the streams, like the Little Cedar, the Cedar, and Flood creeks, which carried off the waters from the melting Kansan ice, to the highest points on the broad, monotonously level, uneroded divides; and in every case within the Iowan area where these old, weathered gravels are known to be present; they are overlain by deposits indicating a much later and newer glacial episode. It will be sufficient to note only a few of the numerous cases which have been observed. At the old brickyard west of the fair-ground in Charles City the material used was a five-foot bed of loam and yellow clay carrying Iowan bowlders four to five feet in diameter, and overlying the valley phase of the Buchanan gravels, which, in the neighborhood of Charles City, attain an enormous development. For some miles above Charles City, on the west side of the Cedar River, the old valley gravels may be seen passing under a thin bed of young, bowlder-bearing loam and clay which covers the gentle slopes and passes up over the flat divides. A boring with a post auger within the bowlder-strewn area went through the thin edge of the Iowan loam into the underlying gravels. The holes dug for some recently set telephone poles along the road and a small stream trench some distance up the slope in the field show the same relation of bowlder-bearing loam to the Buchanan beds. A young glacial deposit overlies super-Kansan gravels; at one point in the trench the gravels rest on the blue Kansan till.

The same story is told, though in a slightly different way, by the majority of the many "mound springs" of this part of Iowa. Mound springs are peaty, boggy places on the hill slopes, due in most cases to the presence of upland gravels lying on impervious blue Kansan, and all covered by the younger sheet of Iowan. The gravels in such cases are reservoirs holding large quantities of water, and this escapes on the slopes near the plane of contact between the reservoir and the underlying clay at the point where the conditions are most favorable, presumably where the Iowan cover is

thinnest. The dry upland slopes above the level of the peat, as well as the dry slopes below that level, are liberally sprinkled with Iowan bowlders imbedded in loam and clay and ranging up to more than 12 feet in diameter. These bowlders are in themselves adequate evidence of a glacial invasion at a time subsequent to the gravel-forming phase, for they were not transported and deposited by either wind or water.

FIG. 4.—View looking north from the margin of the Doris pit, showing the young, uneroded, bowlder-strewn Iowan drift plain; a very typical view in the area occupied by this young drift.

Typical examples of mound springs, easily accessible from Charles City, and showing the stratigraphic relations of Kansan, Buchanan, and Iowan deposits, occur on both sides of the railway in the north half of Section 2, Township 95, Range 15. Preliminary to laying a water pipe from the springy belt to the barn on the land of Mr. W. E. Waller, south of the railway, a shallow well was dug on the dry ground just above the peat; and this passed through the cover of Iowan bowlder-bearing loam and clay, and through the thinned edge of the rusty gravels, down far enough to make a water-tight basin in the blue Kansan. A deeper well near the barn, with 12 feet of gravel and 60 feet of blue clay, may be cited

to show the constant relation of the prevailing gravels of the region to the typical Kansan drift. The same relation is shown in the fine Pleistocene section which occurs a few rods north of the Mitchell County line, not far from the southwest corner of Section 14, Township 97, Range 17. Here, in the south bank of Rock Creek, is an exposure of typical Kansan, blue in color and breaking into the characteristic polyhedral blocks, with an exposed thickness of 50 feet; at the top is a discolored, weathered zone three to four feet thick; next in order is a gravel bed, rusted and rotted, thickness about two feet; and all is covered by a thin loamy deposit carrying many fresh bowlders of varying size, belonging to a post-Buchanan stage of glaciation—the Iowan.

But it is certainly unnecessary to offer additional evidence along this line. Cases of the kind already cited may be multiplied indefinitely. Fortunately the Buchanan gravels are especially well developed in northeastern Iowa, and in the Iowan area they uniformly afford indubitable evidence of a younger, newer, later stage of ice invasion. Outside the Iowan area, as at Colesburg, Delaware County, on the east, and at Iowa City on the south, the Buchanan gravels are covered with heavy deposits of loess, and without the least suggestion of later glaciation. Some very important event, later than the deposition of the gravels, an event which caused the deposition of a body of till ranging up to 20 or 30 feet in thickness and carrying bowlders more than 12 feet in diameter, occurred within the Iowan area and did not occur outside of it. What was that event? Observations in and around the area lead unavoidably to but one conclusion, a conclusion that admits of no question:

The Iowan drift is.

The Iowan Drift Is Young as Compared with the Kansan

The superposition of the Iowan till and the great Iowan bowlders on the weathered Buchanan is all the evidence needed to demonstrate that the Iowan is younger than the Kansan. The freshness of the granites in and on the Iowan—many with the sharp angles caused by fracture unaffected by weathering (Fig. 10), while the granites of the Buchanan are very largely in an advanced stage of

decomposition—lends strong support to the view that the Iowan is separated from the Kansan by a very long interval of time.

The relative youth of the Iowan may, or may not, be indicated by the fact that in places the formation is still very calcareous up to the grass roots. A concrete illustration of calcareous Iowan is seen in a shallow well near the northwest corner of the southeast quarter of Section 21, Township 95, Range 17. It should be stated

FIG. 5.—View at the Dykeman quarry in Section 26, Township 97, Range 17, showing part of an area of thin drift, in which neither Iowan, Kansan, nor Nebraskan can be recognized.

that the later investigations show that this young drift is variable as to the amount of the lime content; for in such localities as that just cited it seems to be as rich in calcium carbonate as the Wisconsin, while in other places it gives no reaction with acid. The original statement concerning this constituent of the Iowan drift was based on facts which remain true for the localities which had then been tested; but the writer has long since ceased to attach much importance to the acid test as a basis for determining the

relative age of drift. The splendid piece of work by Dr. R. T. Chamberlin in the St. Croix region[1] shows how a very young drift may exhibit no trace of lime, while a much older one may give vigorous reactions. In each and every case the amount of calcium carbonate present at or near the surface of a deposit of drift will depend on the original composition of the till and the movements of the ground waters. The same drift sheet gives very different reactions in different localities. The work in Taylor County in 1910 showed very large quantities of lime carbonate in the form of segregated sheets and nodules, distributed along the joints in the highly weathered zone of the old Kansan. The lime came practically to the surface and was turned up among the grass roots by the plow. Along the roadsides, where the highway had been recently worked, it was breaking down to powder and mixing with the crumbling clay; and a sample of the old drift taken at the very surface might have given such energetic reactions to the man with the acid bottle as to lead him to think that he was dealing with the youngest glacial deposit in Iowa. Just why it is that both the old Kansan and the young Iowan should be so very calcareous up to the grass roots in some localities, while showing no traces of lime in others, could be explained, in some cases at least, on the basis of physical characteristics and relation to surface and sub-surface drainage; but it will be sufficient here simply to record the fact and repeat the obvious inference that acid tests applied to drift sheets are of exceedingly small importance in the determination of relative age. The acid bottle, intelligently used, has its place; but the user must be careful to recognize its limitations.

Among the evidences of youth in the Iowan drift is the fact that, in its typical areas, it is uneroded and imperfectly drained. The area selected for illustration in Fig. 7 of the article from the *American Journal of Science*, and again in Fig. 5 of the paper reprinted from the *Zeitschrift für Gletscherkunde*, and offered as "the type of erosion" in the Iowan drift or as something "showing topography of a so-called Iowan drift plain," is a somewhat unfortunate and misleading choice for the reason that it is representative of but a

[1] Rollin T. Chamberlin, "Older Drifts in the St. Croix Region," *Journal of Geology*, XVIII, No. 6, September-October, 1910.

small fraction of the real Iowan drift plain. It embraces the headwaters of Otter Creek, the valley of which belongs to one of the numerous small, exceptional areas in which there is no drift of any kind, neither Nebraskan, Kansan, nor Iowan. Within the southern edge of the map, and at Hazelton, less than a mile farther down the valley, the Niagara limestone is exposed in natural cliffs or quarry faces, forming continuous exposures along the streams in Sections

FIG. 6.—View taken east of the diagonal road in Section 28, Township 95, Range 15, showing typical driftless hills in the belt of country west of the Cedar River.

2 and 10 of Hazelton Township. A part of Section 2 is included in the map. There are outcrops below the village of Hazelton; and in the roads on the sloping sides of the valley, up to the summit of the slopes, rain, wash, and wear of traffic have exposed the fossiliferous Niagaran dolomite, so thin and meager is the Pleistocene in this anomalous area. A full discussion of the Niagaran outcrops in this practically driftless valley will be found on pp. 217–20, *Iowa Geological Survey*, VIII, published 1898. Describing one of the quarries in Section 10, the report says: "The height of the

vertical quarry face is about fourteen feet. The upper two or three feet is made up of soil, reddish-brown residual clays, and decayed fragmentary limestone." It will be noted that there is no recognizable drift; and if the area mapped is to be used to prove that there is no Iowan, with equal force, fairness, and cogency certain parts along its southern margin, together with the whole

FIG. 7.—View on north side of the road passing through the middle of Section 21, Township 84, Range 18, showing the marly, fossiliferous phase of the Lime Creek shales at the surface, with no overlying drift of any age.

valley of Otter Creek southward, might be used to prove that there are no glacial deposits of any sort within the whole state of Iowa.

It would be possible to select a great many points within the Iowan area, that are driftless or practically so, where Pleistocene deposits are wholly absent or are represented by thin beds of sandy loam or a few stray bowlders. One such begins in the eastern edge of Independence and extends eastward over the stony hills for more than a mile. This is part of a belt some miles in length bordering

the Wapsipinicon River. The valley of the Cedar River, the anomalous characteristics of which are recognized and noted, if not explained, in *Iowa Geological Survey*, XIII, 298, 306, affords numerous examples (Figs. 5, 6). For some unaccountable reason the parts of the state occupied by the Lime Creek shales have an unusual number of driftless patches, some of which have dimensions of several miles. A rather small, but typical area of the kind occurs

FIG. 8.—View on ridge in Section 3, Washington Township, Chickasaw County, Iowa, showing the largest bowlder in the county rising out of a heavy growth of small grain.

in Section 21, Township 84, Range 18 (Fig. 7). Large areas, almost continuous, occur over the ten-mile stretch between Mason City and Rockwell; and on the south side of Lime Creek there is a belt, practically driftless, two or three miles wide, all the way to Rockford. There may be bowlders in these areas, even where the other constituents of the drift are absent; and in no small proportion of the territory under consideration, "the soil through which the farmer drives his plow is made up of decomposed shales of

Devonian age." The collector may gather Lime Creek fossils in the pastures and cultivated fields. The peculiarities of these areas, so far as they are seen in Cerro Gordo County, are noted in *Iowa Geological Survey*, VIII, 175, where, years ago, the statement quoted was published.

With the exception of the sub-Aftonian, or Nebraskan, which does not give character anywhere to parts of the glaciated territory large enough for mapping, each drift sheet has its characteristic topography which prevails over the major part of its area, and each has its exceptional phases which affect but a small percentage of its surface. There is a broad belt of typical Iowan between the Wapsipinicon and the Cedar, north of Walker. With the exception of a narrow strip west of the larger river, the broad area between the anomalous Cedar and Flood creeks in Mitchell, Floyd, and Franklin counties is as strikingly level, uneroded, and free from drainage courses as much of the typical Wisconsin, and in some places it is also quite as calcareous. Flood Creek is simply a prairie stream that scarcely breaks the monotony of the plain that extends from the Cedar to the Shell Rock; through its entire course north of Nora Springs, even the Shell Rock flows in a young, shallow trench cut in the otherwise unbroken Iowan plain. Areas such as these—scores of miles in length and width, with scarcely a drainage trench outside the channels of the larger streams—illustrate the real type of erosion in the Iowan; these show the topography of a real Iowan drift plain, and it is scarcely necessary to add that that topography is characteristic of youth.

The typical bowlders of the Iowan are coarse feldspathic granites in no way remarkable for their power to resist the destructive agencies of weathering, and yet very little decomposition has taken place amongst them since they were left exposed at the time of the retreating Iowan ice. In some way, either before or during transportation, many of the bowlders were fractured, and in such cases the angles are still comparatively sharp (Fig. 10), while bowlders of corresponding texture in the Buchanan gravels or in the weathered zone of the Kansan drift are completely decayed. Topography, bowlders, and stratigraphic position all unite in support of the theses:

The Iowan drift is young as compared with the Kansan.

The Iowan drift is not a phase (weathered or unweathered) of the Kansan.

The statement on p. 282 of the paper on "Comparison of North American and European Glacial Deposits," to the effect that the Iowan bowlders "are found chiefly in shallow draws, called sloughs,

FIG. 9.—View in Section 14, Township 95, Range 16, showing a fresh, planed bowlder of the Iowan type in a dry, cultivated field.

at the heads of the valleys or drainage lines," has no special significance even if it were fully justified; but the fact is that the Iowan bowlders occur in various relations to the rather featureless topography of the region to which they are confined. The largest mass of granite in Chickasaw County is on the highest ridge of the whole region, midway between Devon and Alta Vista. There are three Iowan bowlders in Floyd County especially noted for their commanding size, and each is located on dry upland. One of these (Fig. 10) occurs less than two miles southwest of Charles City, in the northwest quarter of Section 14, Township 95, Range 16. It

lies in a cultivated field on the long gentle slope above the road which follows the north line of the section. The dimensions above ground are 27×21×11 feet. Some of the faces are surfaces of fracture, and the angles remain sharp and unaffected by weather. A fragment of smaller size, evidently split off from the larger mass during the time of transportation, equally fresh as to angles and

FIG. 10.—View in Section 14, Township 95, Range 16, showing one of the largest and most typical of the Iowan bowlders on dry ground, with sharp angles unaffected by weathering.

general surface, lies a few rods to the northeast. A very fine bowlder (Fig. 11), more massive than the Charles City specimen, unbroken in transportation, lies near the southeast corner of the city park in Nora Springs, and there are neither "draws" nor "sloughs" anywhere near it. Probably the largest bowlder in the state, the largest so far recorded, occurs in a dry pasture near the southwest corner of Section 22, Township 94, Range 15 (Fig. 12). It is more than forty feet in length, a block of characteristic Iowan

granite of royal proportions. In some parts of the Iowan area, notably in the region between the Cedar and Little Cedar east of Charles City, the bowlders are distributed in trains which stretch across the country from northwest to southeast without respect to sloughs, while intervening spaces of essentially the same topography are practically free. The fact is, however, that the bowlders may be anywhere; upland or lowland seems to make no special differ-

FIG. 11.—View in Nora Springs, Iowa, showing a large and very typical Iowan bowlder on dry upland, near the southeast corner of the city park.

ence; their distribution follows no constant rule, except one: *typical Iowan bowlders are strictly limited to the area of the Iowan drift.*

The Iowan Drift Has Certain Very Intimate Relations to Certain Bodies of Loess

The discussion of the loess and of Calvin's attitude toward it, on pp. 298–99 of the Berlin paper, is based on so many misapprehensions that the task of straightening out the tangle is one too hopeless to be undertaken. There are bodies of loess belonging to different ages, but there is one loess that stands in intimate and close relation to the Iowan drift. The view that the loess is chiefly

an interglacial deposit is in no way inconsistent with the earlier view—and the view still entertained so far as the source of the deposit is concerned—"that the loess is a silt derived from the finer materials of the Iowan drift." That a certain deposit of loess was derived from the Iowan is a conviction that grows stronger and stronger as the work is prosecuted farther and farther in the

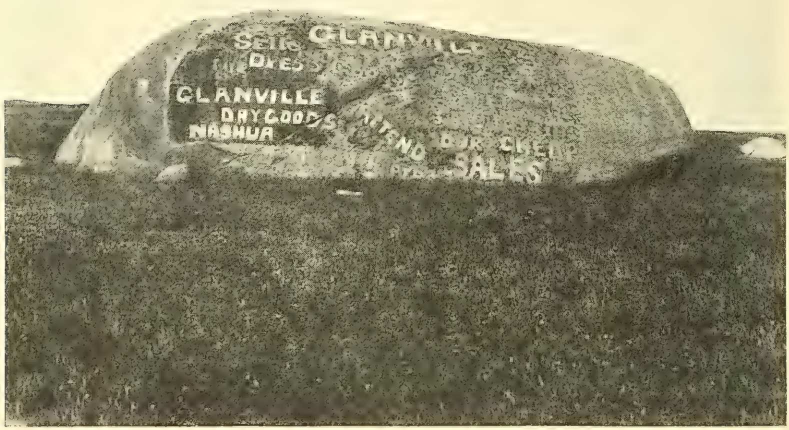

FIG. 12.—View near the southeast corner of Section 22, Township 94, Range 15, showing what is probably the largest Iowan bowlder in the state; and this lies in a dry pasture.

field; and outside the paper under consideration there has never been any "abandonment of the view that there is an Iowan drift correlating with the loess."

The Buchanan gravels are an interglacial deposit. They are not of glacial origin, and they lie between two sheets of drift. The fact that they are interglacial, however, gives no adequate ground to infer that they were not derived from the Kansan, or that there has been an abandonment of the view that there is a Kansan

drift correlating with the Buchanan gravels. The Iowan loess is related to the Iowan drift in much the same way that the gravels are related to the Kansan. The earlier view was that the loess was deposited at the time of maximum development of the Iowan glaciation, when the Iowan area was still covered with ice. The only modification of that view at the present time is that loess deposition took place after the Iowan ice had retreated to a greater or less extent, after an interglacial interval had actually begun. By such retreat extensive mud flats were left, and as these dried before becoming covered with vegetation, strong winds coming, probably, from the ice fields to the north, carried fine sand and dust from the bare surfaces and deposited them beyond the edge of the Iowan area, out upon the old, eroded Kansan. For the development of loess three things seem to be necessary: (1) a gathering-ground of extensive bare and dry surfaces, such as would be furnished by the part of the Iowan area from which the ice had retreated; (2) winds to transport the materials from the dried mud flats; (3) anchorage such as would be furnished most extensively by the vegetation of the extra-marginal Kansan surface. The bare Iowan area afforded no anchorage, but it was an excellent source of supply. Waters carried and sorted materials from the Kansan till and deposited the interglacial formation called Buchanan gravels; winds picked up from the Iowan till such materials as they could transport, and deposited amidst the vegetation of the extra-marginal territory the interglacial formation known as the Iowan loess. The genetic relation of the loess to the Iowan drift is not so very unlike the corresponding relation of the Buchanan gravels to the Kansan; and so far as genetic relationships are concerned, there has been no abandonment of the view originally proposed.

The color, composition, and calcareous content of the Iowan loess are in perfect accord with the hypothesis just expressed; its geographic distribution around the lobed margin of the Iowan area agrees also with the view; the great thickness of this loess at and near its inner margin, and its thinning out with increasing distance from the source of supply, corroborate all the other lines of evidence; while the great amount of eolian sand associated with it in a narrow belt surrounding the lobes of Iowan drift lends additional support.

The Missouri River loess and all other loess deposits which have evidently been derived from the broad flood plains of near-by rivers, have a similar distribution relative to their source; they are thickest and coarsest near the gathering-ground and become thinner as the distance from the base of supply increases. All the facts connected with the origin, composition, and distribution of the loess are perfectly explicable without resorting to the hypothesis that "a considerable part was derived from the great plains east of the Rocky Mountains." Studies in the field afford overwhelming evidence that, genetically and geographically, *the Iowan drift has very intimate relations to certain bodies of loess.*

The Iowan Drift Is Not Related to the Illinoian

It is scarcely necessary to discuss the suggestion that the Iowan may be correlated with the Illinoian. Parenthetically it may be said that if the Iowan and the Illinoian represent the same stage of glaciation, the name Illinoian becomes a synonym for Iowan, and we shall be reduced to the painful necessity of referring to one of our most beloved drift sheets as the "so-called Illinoian." But no such calamity awaits the Illinoian. The Iowan is much the younger of the two. As indicated by the structural and genetic relations above noted, the Iowan —a little later probably than its maximum stage—is practically contemporaneous with the loess; and as the Berlin paper, with noteworthy lucidity, correctly states on p. 299; "the Sangamon interval separates the loess from the Illinoian stage of glaciation so widely that there would seem to be no relation between loess deposition and Illinoian outwash." The same long interval, the same wide separation, exists between the Iowan and the Illinoian stages of glaciation. The two drifts are not related in time or in any other way. All the facts which may be gathered from the most thorough investigations in the field, support this last proposition:

The Iowan drift is not related to the Illinoian.

THE THEORY OF ISOSTASY

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SECTION I. INTRODUCTION

GENERAL

According to the present general conception the theory of isostasy consists of two main postulates, first that the elevated portions of the earth are deficient in density, and second that the material of the earth is comparatively weak. It is generally accepted that these two postulates are inseparable, for it is argued on the one hand that, if the elevated portions are deficient in density, readjustment involving deformation and failure must have taken place in order to compensate for the large mass of material eroded from the lands and deposited in the sea; and it is contended on the other hand that, if the earth is weak, it could not support the mountains and continents unless they are compensated by a defect of density below. In accordance with these two main postulates it is conceived that the dominant type of earth deformation consists in vertical movements between various segments accompanied by lateral flowage of rock beneath and possibly crumpling of the rock in the border zones. This conception is not only applied to the major earth segments, the continents and oceans, but to the smaller units of the continents as well.

The theory of isostasy is a decided contrast to the alternative conception that the earth is strong enough to support the continents and mountains even though there are no compensating density differences, that changes of weight at the surface do not produce vertical movements of the segments in a weaker substratum, and that the dominant type of deformation is folding and upwarping due to lateral compression.

The theory of isostasy if correct would be of fundamental importance to the geologist in interpreting earth movements.

Previous to Hayford's geodetic investigation the conceptions of isostasy were largely speculative. After a comprehensive study of the deflections of the plumb bob carried out by the United States Coast and Geodetic Survey under Hayford's direction,[1]

[1] The most complete statement of Hayford's work which has been published is contained in his two reports issued in 1909 and 1910 by the U.S.C. and G.S. and entitled, *The Figure of the Earth and Isostasy from Measurements in the United States* and *Supplementary Investigation in 1909 of the Figure of the Earth and Isostasy.*

the rather startling conclusions were reached that the excesses of mass composing the continents and mountains are completely compensated by deficiency of density below and that this deficiency of density extends to a depth of something like 60 to 150 miles. These conclusions lent strong support to the theory of isostasy. Considering the completeness of the density compensation, there seemed to be no escape from the conclusion that readjustments of the nature postulated by isostasy are continually taking place.

With the theory of isostasy apparently on such a firm basis, Hayford and others have elaborated the conceptions of earth movements involved in the theory, but these further inferences have not met the approval of many geologists.

The possibility that Hayford had made an error in his geodetic work suggested an investigation which is the basis of this paper. The attempt has been made, first, to examine Hayford's geodetic work apart from any inferences which may have been drawn from it, and second, to examine the theory of isostasy with reference to inferences from geodetic evidence and also on general grounds. This paper has accordingly been divided into two main parts entitled "The Geodetic Work of John F. Hayford" and "The Theory of Isostasy." A "Summary of Conclusions" is given at the end.

It seemed highly desirable in connection with the criticism of Hayford's geodetic work that several of the terms employed should be defined.

DEFINITIONS

"'*Isostatic compensation' is the compensation of the excess of matter at the surface* (*continents*) *by the defect of density below, and of the surface defect of matter* (*oceans*) *by excess of density below.*"[1] "Isostatic compensation" will also be referred to simply as "compensation" and an area or segment of the earth will be spoken of as "compensated" if there is isostatic compensation of the excess or defect of matter over that area or at the surface of the given segment. From the above definition it follows that there will be, in general, a density difference between an average sea level segment

[1] *The Figure of the Earth and Isostasy*, U.S.C. and G.S., 1909, p. 67.

of the earth and a compensated segment, the surface of which is not at sea level. *This density difference will be called the "compensating density difference."*

The "depth of compensation" for any segment of the earth is the greatest depth below sea level at which there is a compensating density difference. This is different from the definition of Hayford which makes the "depth of compensation" the depth "within which the isostatic compensation is complete." The former definition allows for the possibility of a compensation which is not complete.

The "distribution of compensation" for any segment of the earth is the manner of variation of the compensating density difference with respect to depth. If the compensating density difference is uniform, the distribution of compensation is uniform; if it is uniformly varying from a maximum at the surface to zero at the depth of compensation the distribution of compensation is uniformly varying.

The "degree of completeness of isostatic compensation" is an expression used by Hayford. After defining the depth of compensation as quoted above, he says, "At and below this depth the condition as to stress of any element of mass is isostatic; that is, any element of mass is subject to equal pressures from all directions as if it were a portion of a perfect fluid. . . . . In terms of masses, densities, and volumes, the condition above the depth of compensation may be expressed as follows: The mass in any prismatic column which has for its base a unit area of the horizontal surface which lies at the depth of compensation, for its edges vertical lines (lines of gravity) and for its upper limit the actual irregular surface of the earth (or sea surface if the area in question is beneath the ocean) is the same as the mass in any other similar prismatic column having any other unit area of the same surface for its base." This condition of course follows from Hayford's definition of depth of compensation, but it would not hold for the definition adopted in this discussion unless the compensation were complete. Hayford continues as follows: "If this condition of equal pressures, that is, of equal superimposed masses, is fully satisfied at a given depth the compensation is said to be complete at that depth. If there is a variation from equality of superimposed masses the differences

may be taken as a measure of the degree of incompleteness of compensation."[1] In order to make this idea exact, let A and B (Fig. 1) represent two columns each of horizontal cross-section, a, and extending to the depth of compensation, h_1, the upper surface of A being h miles above sea level and the upper surface of B being at sea level. Let the weight of A equal W_A and the weight of B equal W_B. If there were no isostatic compensation, and if the densities of A and B were the same at similar depths, then W_A would be in excess of W_B by the amount $a\delta h$, where δ is the mean surface density of the earth. If this excess of weight were entirely made up for by a deficiency of density below, compensation would be complete. *Therefore let the "degree of completeness of isostatic compensation" for any segment, A, be defined as*

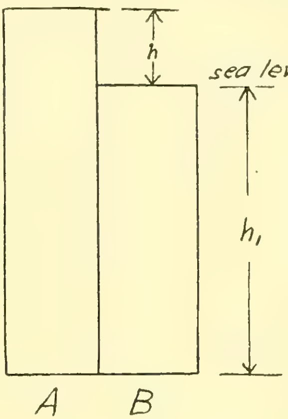

FIG. 1

$$M = \frac{a\delta h - (W_A - W_B)}{a\delta h}$$

The quantity in parenthesis is the amount by which the weight of A is in excess of the weight of B. The whole numerator is, therefore, the weight which has been made up for by a deficiency of density below the surface and the entire fraction is a number expressing the part of the weight, $a\delta h$, which has been made up for. The above formula holds equally well for land and ocean areas if h be taken positive above sea level and negative below.

FOR LAND AREAS

1. If $W_A < W_B$ then $M > 1$
2. If $W_A = W_B$ then $M = 1$
3. If $W_A - W_B = a\delta h$ then $M = 0$
4. If $W_A - W_B > a\delta h$ then $M < 0$

[1] *The Figure of the Earth and Isostasy*, 1909, p. 67.

FOR OCEAN AREAS (h BEING A NEGATIVE QUANTITY)

1. If $W_A > W_B$ then $M > 1$
2. If $W_A = W_B$ then $M = 1$
3. If $W_A - W_B = a\delta h$ then $M = 0$
4. If $W_A - W_B < a\delta h$ then $M < 0$

When $M=0$, there would be no isostatic compensation. The condition that M is negative is equivalent to a distribution of density so related to the surface that the material under any surface is heavier than the material under a lower surface. There would be no isostatic compensation in this case. In view of the facts brought out by Hayford the fourth case is, however, very improbable.

"Over-compensation" is such an isostatic compensation that $M > 1$.

"Complete compensation" is such an isostatic compensation that $M = 1$.

"Under-compensation" is such an isostatic compensation that $0 < M < 1$.

Isostatic compensation is considered the more complete, the closer M approaches to 1.

SECTION II. THE GEODETIC WORK OF JOHN F. HAYFORD

BRIEF DESCRIPTION OF HIS WORK AND METHODS

On certain assumptions as to the size and shape of the earth and as to the position of a base station on this ideal earth, Hayford, by triangulation and geodetic observations, measured the prime vertical and meridian components of the deflection of the plumb bob from the true vertical at several hundred stations scattered over the United States. He then calculated the deflections which all the topographic features within a radius of 2,564 miles of each station should produce if the density of the earth were the same at similar depths. He found that these calculated deflections, which he called the "topographic deflections," were universally larger than the "observed deflections." The only explanation of such widespread observations is that there is some sort of isostatic compensation of the surface excesses and defects of mass. Recog-

nizing this fact Hayford set out to make a series of least square solutions assuming various kinds of isostatic compensation. He calculated what the deflections should be assuming isostatic compensation by the use of a reduction factor, that is, a factor which when multiplied by the topographic deflection will give the deflection, isostatic compensation considered. In all of his solutions Hayford assumed the isostatic compensation to be complete. In his five principle solutions he assumed a uniform distribution of compensation and assumed depths of compensation varying from zero to infinity.[1] On these assumptions the conclusion was reached that the most probable depth of compensation is 76 miles since the sum of the squares of the residuals was least for this depth.

Subsidiary solutions were made assuming (1) that the compensation is uniformly distributed in a ten-mile substratum, (2) that the compensation is greatest at the surface and decreases uniformly with respect to depth until it becomes zero at the depth of compensation, and (3) that the compensation is distributed according to the law postulated by Chamberlin.[2] The method used in each of these three cases was to find the depth for which the reduction factor was most like the reduction factor for the most probable solution assuming a uniform distribution. Hayford concluded that so far as the geodetic evidence available could test them, any of the three distributions of compensation postulated is as probable as a uniform distribution. The depth of compensation found for a distribution in a ten-mile substratum was 40 miles; for a uniformly varying distribution, 117 miles; and for the Chamberlin distribution of compensation, 193 miles.

A further interesting phase of Hayford's work is his C-solution[3] which was made on the assumption that there is no isostatic compensation under land areas but that there is complete isostatic

[1] The condition that the depth of compensation is infinite is taken as equivalent to no isostatic compensation. The condition that the depth of compensation is zero is taken as equivalent to the condition that the topographic features do not affect the plumb bob.

[2] This law postulates a maximum density difference slightly below the surface. This density difference decreases rapidly at first and then more gradually with respect to depth.

[3] P. 168 of 1909 report.

compensation at depth zero under ocean areas. It was found that these assumptions were not as close to the facts as the assumption of complete compensation at the depth of 76 miles under both land and ocean. In discussing the C-solution Hayford says:[1]

> It follows, moreover, that it is an isostatic compensation of the separate topographic features of the continent, not a compensation merely of the continent as a whole. In solution A[2] it is a compensation of the separate features which is assumed. An inspection of the numerical values of the computed topographic deflections, and of the deflections computed with isostatic compensation considered shows that merely to have assumed the continent as a whole to be compensated, not its separate topographic features would have given a solution resembling solution C much more closely than solution A.[3]

A very vital step in Hayford's work is his determination of the degree of completeness of compensation. As this is one of the principal points to be criticized, his method will be explained in detail in connection with the criticism. Suffice it to say here that he concluded that the isostatic compensation is on an average nine-tenths complete.

CRITICISM OF HAYFORD'S WORK

Hayford certainly showed that there is some sort of isostatic compensation; but he did not fully consider all possibilities as to the nature of this compensation. The exact nature of isostatic compensation for any place is determined by three factors, (1) depth of compensation, (2) distribution of compensation, and (3) degree of completeness of compensation. Hayford considered all possible depths of compensation and several distributions of compensation; but all of his solutions involving isostatic compensation were made on the assumption that the compensation is complete. This was a purely arbitrary assumption on Hayford's part since he gave no reason whatever for believing at the outset that compensation is

[1] Quoted from p. 169 of 1909 report.

[2] Solution *A* was made on the assumption that compensation is complete at depth zero over both land and sea. This solution turned out to be nearer the truth than solution C.

[3] It should be noted that the assumption of complete compensation under ocean areas with no compensation under continents is not equivalent to a compensation of the continents as a whole with respect to the oceans, but only to a compensation for the part of the continents below sea level.

complete, and furthermore the fact that he later attempted to find the degree of completeness implies that there is no reason to believe at the outset in complete compensation. In view of this fact the method of determining the degree of completeness of compensation is questionable.

Criticism of method of finding degree of completeness of compensation.—Hayford's method is best explained by an example. Suppose the topographic deflection at some station is 35.79″ This is assuming no isostatic compensation. Suppose that the residual assuming complete compensation at a depth of 76 miles is 3.33″, or in other words, suppose that the difference of the true deflection and the deflection which would exist if the compensation were complete at a depth of 76 miles is 3.33″ This value (3.33″) is apparently the part of the topographic deflection which has not been made up for by isostatic compensation. The ratio of 3.33 to 35.79 is, therefore, taken by Hayford as a measure of the incompleteness of compensation. In explanation of this method Hayford writes as follows:

> The residuals of solution G[1] furnish a test of the departures of the facts from the assumed condition of complete isostatic compensation uniformly distributed to a limiting depth of 113.7 kilometers. In order to obtain definite ideas let the whole of the residuals of this solution be credited to the incompleteness of the compensation. The conclusion as to the completeness of compensation will then be in error in that the actual approach to completeness will be considerably closer than that represented by the conclusion—that is, the conclusion will be an extreme limit of incompleteness rather than a direct measure. For by this process of reasoning every portion of a residual of solution G, due to the departure of the actual distribution of compensation with respect to depth from the assumed distribution, or due to the error in the assumed mean depth of compensation, or to regional variation from a fixed depth of compensation, or due to errors of observation in the astronomic determinations and the triangulation which affect the observed deflection of the vertical, or due to errors of computation, is credited to incompleteness of compensation.[2]

The objection to the paragraph quoted is that it apparently is taken for granted that the error in the assumed mean depth of

[1] Solution G, the most probable solution according to the first report, was made assuming a depth of compensation of 70 miles.

[2] Quoted from p. 164 of 1909 report.

compensation increased the size of the residuals. Is it not very probable that the introduction of an error in depth actually diminished the residuals? The most probable depth was calculated on the assumption of completeness. If the assumption of completeness was wrong, the depth of compensation which would appear most probable would not be the true depth of compensation but a depth which would counteract the effect of the wrong assumption in regard to completeness. In other words the error in the assumed mean depth of compensation would be such as to decrease the residuals. Therefore the residuals which would have been obtained had the correct depth been used would be larger than the residuals actually obtained. The degree of incompleteness as measured by Hayford's method would, therefore, be larger.

If the depth of compensation were known independently, then Hayford's method of finding the completeness would be legitimate. To go back to the example cited before, suppose that it is known independently that the depth of compensation is 25 miles and suppose that the residual obtained on this basis and assuming complete compensation is $15''$: this value would be the part of the topographic deflection which had not been made up for by compensation and therefore the ratio of 15 to 35.79 would be an approximate measure of the incompleteness of compensation.

The above argument will be made clear by a brief summary. The depth and degree of completeness of compensation are unknowns to be determined. It is claimed that these two unknowns can not be determined by Hayford's method of assuming complete compensation, calculating the most probable depth, and using the residuals to tell the degree of incompleteness, because this method would only be legitimate for the one case when compensation is actually complete. If compensation were not complete, then Hayford's calculated depth would be wrong and would furthermore be in error in such a direction as to at least partially make up for the wrong assumption regarding degree of completeness. The resulting residuals would therefore not furnish a maximum measure of the degree of incompleteness; but the compensation would appear to be more nearly complete than would be the fact.

We are forced to conclude that, from the geodetic evidence

alone, neither the depth nor the degree of completeness of isostatic compensation can as yet be considered settled.[1]

Criticism of C-solution.—The criticism might be made of the C-solution that the assumption of complete compensation at depth zero under oceans obviously does not correspond to the facts and that, by trying several depths, a combination might be found which would appear to be, so far as the information available could test it, as close to the actual conditions as any other hypothesis. From the wide departure of the C-solution it seems, however, rather improbable that such a depth could be found.

FURTHER CONSIDERATIONS

Possibilities of an incomplete compensation.—Since Hayford only considered the case of complete compensation, it is desirable to see whether or not an incomplete compensation would meet the geodetic requirements as well as a complete compensation. Any test of incomplete compensation based on Hayford's residuals is apt to be misleading since these residuals may involve two errors that tend to counterbalance each other. By a study of the reduction factor, however, we may be able to tell whether or not an incomplete compensation would be as probable from the geodetic point of view as complete compensation.

According to the definition given in this paper the degree of completeness of compensation is

$$M=\frac{a\delta h-(W_A-W_B)}{a\delta h}. \qquad (1)$$

If there is isostatic compensation, there will be a compensating density difference between the material in column A and the material in column B.[2] If at any given depth the density of column A be δ_A and of column B, δ_B, then the compensating density difference at that depth will be $\delta_1=\delta_A-\delta_B$ which is of course negative when A is a land segment. It follows that $\delta_B=\delta_A-\delta_1$. Now

[1] It should be noted that so far as the nature of compensation is questionable, Hayford's values for the size and figure of the earth are also open to question.

[2] See definition of M, p. 607–8.

$W_A - a\int_0^{(h_1+h)} \delta_1 dz$ is the weight[1] which the column A would have if its density were the same as in column B and is therefore equal to the weight of B plus the weight which the material in A above sea level would have if there were no isostatic compensation. Thus

$$W_A - a\int_0^{(h_1+h)} \delta_1 dz = W_B + a\delta h$$

or

$$W_A - W_B = a\delta h + a\int_0^{(h_1+h)} \delta_1 dz \tag{2}$$

Substituting (2) in (1),

$$M = \frac{a\delta h - \left\{ a\delta h + a\int_0^{(h_1+h)} \delta_1 dz \right\}}{a\delta h}$$

or

$$\delta h M = -\int_0^{(h_1+h)} \delta_1 dz \tag{3}$$

The case of a uniformly distributed compensation will be considered. In this case, δ_1 being a constant, (3) reduces to

$$\delta h M = -\delta_1 (h_1 + h) \tag{4}$$

As stated before Hayford only considers the case where $M = 1$. He further makes the approximation of neglecting h in comparison with h_1. This approximation which is permissible for depths of compensation considered by Hayford but which would not be allowable for shallow depths is discussed later. The relation corresponding to (4) which Hayford uses is $\delta h = -\delta_1 h_1$. If however the unknown quantity, M, is retained, the corresponding reduction factor which we will call F_M is as follows:

$$F_M = 1 - M \frac{\log \dfrac{r^1 + \sqrt{(r^1)^2 + h_1^2}}{r_1 + \sqrt{r_1^2 + h_1^2}}}{\log \dfrac{r^1}{r_1}}. \tag{5}$$

[1] As δ_1 may vary with the depth it is necessary to sum up the product of δ_1 and the small elements of depth rather than use the product, $\delta_1(h_1+h)$.

Adding and substracting M, we have

$$F_M = 1 - M(1 - F) \tag{6}$$

where F, the reduction factor obtained by Hayford, is

$$F = 1 - \frac{\log \dfrac{r^1 + \sqrt{(r^1)^2 + h_1^2}}{r_1 + \sqrt{r_1^2 + h_1^2}}}{\log \dfrac{r^1}{r_1}}. \tag{7}$$

Comparing F with F_M we see that, when $0 < M < 1$, F_M will be greater than F for the same ring[1] and h_1. Also for any given ring F is larger, the larger the depth of compensation,[2] h_1. It follows, therefore, that F_M for $M < 1$ calculated on any given h_1 will be greater for all rings than the corresponding factor, F, calculated on a smaller h_1, for

$$\left[F_M\right]_{\substack{M<1\\h_1=x}} > \left[F\right]_{h_1=x} > \left[F\right]_{h_1<x}$$

or

$$\left[F_M\right]_{\substack{M<1\\h_1>76}} > \left[F\right]_{h_1=76}$$

Now assuming $M = 1$ Hayford has already shown that the set of factors obtained when $h_1 = 76$ miles gives a closer result than the set of larger factors obtained when $h_1 > 76$ miles. It seems probable therefore that, if a solution were to be attempted assuming $0 < M < 1$, nothing would be gained in taking a depth of compensation larger than the most probable depth assuming $M = 1$. The writer would not care to make the preceding statement as a positive fact without an inspection of the data for the calculation of the topographic deflections. For it seems possible, although not probable, that a combination of $M < 1$ and $h_1 > 76$ might yield as close a result as $M = 1$ and $h_1 = 76$ on account of the fact that,

[1] In calculating the topographic deflection the area around any station is divided into concentric rings whose outer radii are r^1 and inner radii, r_1.

[2] See table, p. 70 of 1909 report.

though the reduction factor becomes larger, the relative increase in the various rings is not the same as the increase when h_1 is made larger than 76 but M is kept equal to 1.

On the other hand, when $0<M<1$ and $h_1<76$, the resulting factor, for any given ring, compared to F for $h_1=76$, tends to become larger on account of taking $M<1$, but tends to become smaller on account of taking $h_1<76$. If h_1 be taken sufficiently small, the factor, F_M for $M<1$, and $h_1<76$, becomes smaller for certain rings and larger for other rings than F for $h_1=76$. It therefore seems quite probable that a combination of $M<1$ and $h_1<76$ should prove to be as close an approximation to the facts as $M=1$ and $h_1=76$.

Similarly, if the case where $M>1$ were to be considered, the best depth of compensation would probably turn out to be greater than 76 miles.

By equation (6) above, it is an easy matter to calculate the factor F_M for any value of h_1 which is equal to the radius of any ring. In order to obtain a typical example, the factors were calculated assuming $M=.5$ and $h_1=19.29$ kilometers (11.987 miles) and are given below together with the factors for Hayford's most probable solution in which it was assumed that $M=1$ and $h_1=113.7$ kilometers (70.67 miles).[1]

It will be noted that, for outer rings, the factor, F_M, is approximately .5 while F is nearly zero. From the examples of calculations of "topographic deflections" given by Hayford it would seem that the outer rings, especially the oceanic compartments, have a considerable effect on the topographic deflection. It might seem, therefore, that $M=.5$, $h_1=19.29$ kilometers would not give as close a result as $M=1$, $h_1=113.7$ kilometers; but without some sort of test this question would remain a matter of conjecture. Furthermore the additional hypothesis might be introduced that the compensation under ocean areas is complete or even that ocean areas are over-compensated. Then when we remember that the assumption regarding either M or h_1 or both may

[1] The value of the depth of compensation given in the first report as most probable is 70 miles. In the second report 76 miles is given, but the reduction factors for this depth are not published.

be varied, there seems to be nothing to show that a combination of a decided under-compensation and shallow depth under land areas with a practically complete compensation under ocean areas would not prove, so far as present information is able to test it, as close an approximation to the actual conditions as a combination of complete compensation with a depth of 76 miles under both land and sea. And it is not improbable that several combinations involving a decidedly incomplete compensation under land areas could be found which would appear equally as close to the truth as $M=1$ and $h_1=76$ miles.

Ring	$\left[F_M\right]^{M=.5}_{h_1=19.29\text{ kil.}}$	$\left[F\right]_{h_1=113.7\text{ kil.}}$
29	.996	....
28	.994	....
27	.991	.997
26	.988	.996
25	.982	.995
24	.975	.992
23	.965	.988
22	.950	.983
21	.930	.976
20	.900	.965
19	.860	.951
18	.809	.930
17	.747	.900
16	.679	.859
15	.617	.801
14	.570	.721
13	.539	.618
12	.520	.493
11	.510	.358
10	.505	.234
9	.502	.139
8	.501	.077
7	.500	.040
6	.500	.020
5	.500	.010
4	.500	.005
3	.500	.003
2	.500	.001
1	.500	.001

In the case of $M>1$, $h_1>76$ miles it is probably also true that the compensation under ocean areas would have to be taken complete.

In the foregoing discussion the distribution of compensation

was assumed uniform. The argument that, if $M<1$, h_1 is probably less than the most probable depth assuming $M=1$ would hold for the Chamberlin compensation or for a compensation uniformly varying from a maximum at the surface to zero at the depth of compensation. For the reduction factors in the subsidiary investigations are linear functions of the reduction factor for uniform distribution.

Changes in formulae required by shallow depth of compensation.—Under this head the approximation mentioned above in connection with equation (4) will be considered.

$$\delta h M = -\delta_1(h_1+h) \tag{4}$$

δ_1 is such a quantity that $(W_A - a\delta_1\ [h_1+h]) = [W_A]_{M=0}$ is the weight which column A would have if there were no isostatic compensation. Therefore

$$W_A = [W_A]_{M=0} + a\delta_1(h_1+h)\ .$$

Thus the deflection due to W_A may be obtained by adding to the deflection which would be produced if there were no isostatic compensation the deflection which would be produced by $a\delta_1(h_1+h)$. Therefore the deflection at any station assuming isostatic compensation is equal to the topographic deflection (D) plus the deflection (D_c) due to the defect or excess of density from the surface down to the depth of compensation. If H be the height of the observing station above sea level, then the deflection due to the defect of density in a compartment whose surface is h miles above sea level is (neglecting the curvature of the earth),[1]

$$D_c = 12.44''\frac{\delta_1}{\Delta}(\sin a^1 - \sin a_1)\left\{(H+h_1)\log\frac{r^1+\sqrt{(r^1)^2+(H+h_1)^2}}{r_1+\sqrt{r_1+(H+h_1)^2}}\right.$$
$$\left. + (h-H)\log\frac{r^1+\sqrt{(r^1)^2+(h-H)^2}}{r_1+\sqrt{r_1^2+(h-H)^2}}\right\} \tag{8}$$

In calculating the topographic deflection Hayford neglects H except when it is necessary to make a slope correction. However, H is introduced in equation (8) in order to make it exact. Whether it would be legitimate to neglect this factor or not can best be told

[1] See A. R. Clarke, *Geodesy*, 1880, p. 295, and *Figure of the Earth and Isostasy*, 1909, p. 20, for the derivation of equation (8).

from the resulting expression for the reduction factor. Taking the value of D_c given in (8) the reduction factor is

$$F_M=\frac{D+D_c}{D}=1+\frac{1}{\log\frac{r^1}{r_1}}\left\{\frac{\delta_1(H+h_1)}{\delta h}\log\frac{r^1+\sqrt{(r^1)^2+(H+h_1)^2}}{r_1+\sqrt{r_1^2+(H-h_1)^2}}\right. \tag{9}$$

$$\left.+\frac{\delta_1(h-H)}{\delta h}\log\frac{r^1+\sqrt{(r^1)^2+(h-H)^2}}{r_1+\sqrt{r_1^2+(h-H)^2}}\right\}$$

From (4)

$$\frac{\delta_1}{\delta}=-\frac{Mh}{h_1+h} \tag{10}$$

Substituting (10) in (9)

$$F_M=1-\frac{M(H+h_1)}{h_1+h}\,\frac{\log\dfrac{r^1+\sqrt{(r^1)^2+(H+h_1)^2}}{r_1+\sqrt{r_1^2+(H+h_1)^2}}}{\log\dfrac{r^1}{r_1}}$$

$$-\frac{M(h-H)}{h_1+h}\,\frac{\log\dfrac{r^1+\sqrt{(r^1)^2+(h-H)^2}}{r_1+\sqrt{r_1^2+(h-H)^2}}}{\log\dfrac{r^1}{r_1}} \tag{11}$$

This reduces to Hayford's factor if M be put equal to 1 and H and h be put equal to zero. These are the three approximations on which Hayford's factor is obtained. If h_1 is large, it is legitimate to neglect H and h; but if h_1 were to be taken as 12 miles h and H would certainly have to be considered. This fact would increase the length of the computations since for a complete solution of the problem a different factor would be necessary for each compartment whereas, before, the same factor was used for an entire ring. Doubtless, however, devices could be employed which would facilitate the calculations.

The necessity of having to use the reduction factor given in (11) serves to make the depth and degree of completeness of compensation more open to question than ever.

SUMMARY

On the basis of Hayford's work it may be considered settled that there is some sort of isostatic compensation, but so far as Hayford's investigation has yet gone there are many possibilities

as to the nature of this compensation. None of the possible distributions of compensation have been eliminated by Hayford's geodetic work; in fact, so far as the geodetic work is concerned, Hayford has shown that four different distributions of compensation are equally probable.

The present possibilities for isostatic compensation may be grouped with considerable certainty under three heads: first, there is the possibility of complete compensation at a depth in the neighborhood of 60 to 150 miles depending on the distribution of compensation; second, there is the possibility of an over-compensation at a greater depth for land areas with probably complete compensation for ocean areas; and third, there is the possibility of under-compensation at a shallow depth for land areas with complete or over-compensation for ocean areas.

SECTION III. THE THEORY OF ISOSTASY

INTRODUCTORY

In any theory of earth movements it is recognized that the earth is a failing structure in the sense that it has been and is being permanently deformed under the ultimately controlling force of gravity. It is not therefore the essential idea of the theory of isostasy that the earth as a whole is a failing structure; but the characteristic of the theory is the type of deformation which it postulates. This may not be the critical point of isostasy as it was originally conceived, or as conceived today by everyone; but it is the point which has been elaborated by the supporters of the theory and which is of first importance to the geologist; and it will therefore serve as a basis of criticism in this paper.

Type of deformation postulated in the theory of isostasy.—The controlling movements of the earth's crust are vertical movements of the various segments in response to changes of weight produced by erosion and deposition.

These vertical movements are brought about by flowage beneath the surface from areas of deposition to areas of erosion or, in general, from areas of excessive weight to areas deficient in weight.

This flowage beneath the surface is comparable in speed to the process of erosion and is started under stress-differences so small

as to require that all segments of the earth of given area are essentially equal in weight.

This flowage may be accompanied by folding in the border zones of the segments.

Deformation of this kind is not restricted to the major segments, the continents and oceans, but is the type of movement which takes place between the smaller units of the continents.

Lines of criticism of isostasy.—In criticizing the theory of isostasy two main lines of argument will be followed. First, the type of deformation postulated by isostasy can not account for certain facts. Second, Hayford's geodetic results can be accounted for without supposing the type of deformation postulated by isostasy.

FACTS NOT ACCOUNTED FOR BY THE TYPE OF DEFORMATION POSTULATED IN THE THEORY OF ISOSTASY

The degree to which isostasy must be discarded depends on the importance of the phenomena which it will not explain.

The theory of isostasy as conceived in this paper does not adequately account for the folding of rocks of the earth's crust.—Folding is evidence of lateral forces of enormous magnitude. On the other hand the controlling movements of isostasy are assumed to be vertical movements. However, it has been suggested by Hayford that folding would be caused by the undertow from an area of deposition to an area of erosion:

> Horizontal compressive stresses in the material near the surface above the undertow are necessarily caused by the undertow. For the undertow necessarily tends to carry the surface along with it and so pushes this surface material against that in the region of erosion, see Fig. 2. These stresses tend to produce a crumpling, crushing and bending of the surface strata accompanied by increase of elevation of the surface. The increase of elevation of the surface so produced will tend to be greatest in the neutral region or near the edge of the region of erosion, not under the region of rapid erosion nor under the region of rapid deposition.[1]

This undertow must exist chiefly below the depth of compensation. If the earth were a perfect fluid the materials of different densities would, if not diffusible, arrange themselves in concentric shells with the heavier material toward the center. There is always

[1] *Science*, February 10, 1911, p. 205.

a tendency for the earth to take this arrangement in the sense that the stress-differences are on an average tending in this direction. It would seem, therefore, as a general proposition, that where the material of the earth is weak, the tendency would be more toward equalization of densities laterally than toward lateral differentiation of densities such as implied by isostatic compensation. Even though the stress-differences due to lateral variations in density were not sufficient to deform the rock so as to equalize the densities, a flowage from beneath an area of deposition to an area of erosion would certainly tend to produce a distribution of density within the zone of flowage itself which would have no relation to topography. It appears, therefore, that there could be very little isostatic compensation in a zone where yielding occurs as readily as postulated by isostasy.

Now, according to the theory of isostasy, compensation would be essentially complete, and if compensation is complete the depth of compensation as determined by Hayford's geodetic work would be as great as 60 miles. Hence, the undertow postulated by isostasy would exist chiefly below 60 miles. It is decidedly questionable that an undertow even much nearer to the surface than 60 miles would cause the observed folding in the upper few miles of the crust.

The theory of isostasy cannot account for the general uplift of sediments without folding.—If the isostatic compensation is complete any deposition of material should cause a sinking of the underlying segment. Isostasy could not therefore account for the fact that horizontal sedimentary rocks are found far above sea level unless a lowering of the sea level were supposed; but this possibility can generally be dismissed because the relative change in sea level is not registered in all parts of the world.[1]

[1] In discussing isostatic adjustments (see *Science*, February 10, 1911) Hayford suggests that some uplifts are due to expansion and contraction caused by heating and cooling of sedimentation and erosion. These deformations, however, are not a distinctive assumption of the theory of isostasy at least as the theory is conceived in this paper; but were suggested to account for certain geological phenomena which the theory of isostasy could not explain.

At any rate, expansion due to heating effect of sediments is entirely inadequate to account for known uplifts. In making his estimate that the vertical expansion is

The theory of isostasy does not explain the apparently heterogeneous relation of uplift and subsidence to erosion and deposition.—Since isostasy postulates an adjustment or flowage which is comparable in speed to the process of erosion, a high area which is subject to erosion should be further uplifted as erosion progresses and should not be reduced to sea level until its deficient density is equalized by erosion of the lighter material at the surface and restoration of heavier material below. With a depth of compensation of 76 miles, the theory of isostasy would require greater continuous uplifts than are known to exist. As a matter of fact, some areas have been uplifted as erosion progressed and others have remained stationary. In some cases erosion to a peneplain has been followed by subsidence and in other cases by uplift.

ALTERNATE HYPOTHESES TO ACCOUNT FOR HAYFORD'S GEODETIC RESULTS

Erosion and deposition are assumed to be the principal cause of disturbance of the equilibrium condition of isostasy. Since deposition does not in general extend beyond the boundaries of the continental shelves, the cause and effect of the type of deformation postulated by isostasy would be confined to the continents proper. So far, then as distributions of density are to be made a proof of the theory of isostasy, the critical test is not in the density relation of the continental masses as a whole compared to the ocean basins, but in the completeness of compensation of the topographic features of the continents. Now it has been shown in the preceding section of this paper that, though there is very likely a complete compensation of the ocean defects of mass, yet it is a distinct possibility so

one foot for every 33 feet of deposition Hayford neglects the fact that the irregularities in the isothermal surfaces near the surface of the earth flatten out with depth. However, taking Hayford's estimate and assuming that an area of deposition was covered by very shallow water and that the expansion due to heating took place all at one time, the maximum uplift above sea level could not be more than one-thirty-third of the thickness of the sediments deposited. Subsequent erosion would tend to reduce this elevation and any further elevation caused by relief from eroded material would certainly not more than equal the eroded layer. Hence, wherever the present elevation above sea level is more than one-thirty-third the thickness of the last conformable sedimentary series, some other factor than expansion due to heating effect of sedimentation must be sought to account for the uplift.

far as the geodetic evidence is concerned that the compensation of the topographic features of the continent is decidedly incomplete. The theory of isostasy can not therefore be considered as established by the geodetic work of Hayford. Furthermore, the probability that isostasy exists is lessened by the fact that an incomplete compensation can be very plausibly explained without involving the conceptions of isostasy.

The tendency of lateral compression to produce isostatic compensation.—In the folding and overthrust faulting of rocks there is abundant evidence of lateral compression. It has already been shown that this folding is probably not caused by an undertow such as isostasy supposes to be set in motion by erosion and deposition. The compression indicated by folding may be due to shrinkage of the earth; it may be due to squeezing of the continental segments by the oceanic segments; or it may be due to other causes; but whatever the cause may be, it is certain that it has produced great uplifts. Suppose that the continent is composed of portions of different densities, but that the stress-differences set up by these differences in density are not sufficient to cause a deformation of the material and a consequent uplift of the lighter masses. If this were the case, it would seem reasonable to believe that there would be a tendency for the effects of lateral compression to localize in the lighter segments since there is always a tendency for lighter segments to move up even though the stress-differences tending in this direction are not sufficient to produce an actual movement. Other things being equal, folding would probably tend to localize in sedimentary rocks since the parallel bedding planes allow slipping to take place readily. Here again there might be a tendency toward isostatic compensation since sedimentary rocks on an average are lighter than igneous rocks. There are undoubtedly other factors which determine the place of folding, but it is entirely possible that uplifts by folding are incompletely compensated.

A compensation of areas which have been uplifted without folding may be accounted for in a similar way. It is possible that lateral forces similar in magnitude to those forces which produce folding at the surface, but localized at greater depth should cause a deformation which is registered at the surface simply as a general

uplift. In this case also the deformation would tend to localize where the resistance to uplift were least, in other words, in the lighter segments.

The type of deformation suggested here is perfectly distinct from that postulated by isostasy. The theory of isostasy supposes that light areas are high because the strength of the material below is not sufficient to support segments different in weight. The possibility suggested in the preceding paragraphs is that high areas are light because the great deforming forces of the earth follow the path of least resistance.

The automatic compensation of uplifts and subsidences due to expansion and contraction.—It is possible that some uplifts and subsidences are due to expansion and contraction of the underlying material. Such deformations are not a distinctive assumption of the theory of isostasy. Changes of volume may be due to changes of temperature or pressure which in turn may be due to a variety of causes. Any changes of elevation caused by expansion or contraction will be automatically compensated since the weight does not change. This would be another factor tending to produce compensation which does not involve the type of deformation postulated in isostasy.

SECTION IV. SUMMARY OF CONCLUSIONS

Isostasy is a theory of earth movements based on the assumption that the lighter portions of the earth are elevated in proportion to their defect of density because the earth is not strong enough to support segments of different weights. The principal support for the theory is the geodetic work of Hayford from which it was concluded that the excesses of mass at the surface are completely compensated for by defects of density below, said defects of density extending to a depth of something like 60 to 150 miles.

It is believed that Hayford made an error in determining the degree of completeness of compensation which invalidates his conclusions, for he assumed complete compensation in calculating the depth and then used this depth to calculate the degree of completeness. Hence, instead of the single possibility of a practically complete compensation, there are, so far as has been shown from

the geodetic evidence, three groups of possibilities for isostatic compensation: first, the possibility of complete compensation at a depth in the neighborhood of 60 to 150 miles depending on the distribution of compensation; second, the possibility of an over-compensation at a greater depth for land areas with probably complete compensation for ocean areas; and third, the possibility of under-compensation at a shallower depth for land areas with complete or over-compensation for ocean areas.

Hayford's geodetic results do not, therefore, constitute a proof of the theory of isostasy.

An incomplete compensation of the topographic features of the continents can be plausibly explained without supposing the type of deformation postulated by isostasy.

There are many important phenomena which the theory of isostasy will not explain.

SPECULATIONS REGARDING THE GENESIS OF THE DIAMOND

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The recent admirable summary by Dr. Percy A. Wagner[1] of what is now definitely known regarding the geological conditions in which the diamond occurs in South Africa suggests certain speculative points of view, which, if found worthy of attention, may in turn suggest desirable lines of investigation in the field and the laboratory. These inquiries may perchance throw light on the intricate, fascinating question of the genesis of the diamond; or, even in a broader way, on the rôle of carbon in eruptive rocks, whether in the form of diamond or graphite, or as gas locked up in carbonates or certain silicates.

To the student of the occurrence of the diamond in countries other than South Africa, one of the most significant facts established by the prospecting of the African miners is that, aside from its well-known occurrence in pipes, the diamond-bearing eruptive material, kimberlite, occurs also in dikes, and that these usually have considerable longitudinal extension but only small width, except where expanded into pipes, and even these are frequently insignificant in relative dimensions. This slight prominence of the diamond-bearing bodies, coupled with the extreme susceptibility of the material to alterations which render its identification a matter of great difficulty, suggests at once that the failure to detect such dikes and pipes in districts in which the diamond is found only in sedimentary deposits, modern or ancient, is not a conclusive argument against their existence, nor is it clear evidence that the original matrix was notably different from the South African kimberlite. In countries like India and Brazil, in which the diamonds of the modern alluvial deposits have been definitely traced back to conglomerates of considerable geological age, the presence or absence of kimberlite dikes should be tested by prospecting operations,

[1] *Die diamantführenden Gesteine Südafrikas*, Berlin, 1909.

not so much, perhaps, in the areas occupied by the conglomerates themselves as in the neighboring ones occupied by formations known to have been in existence when the conglomerates were laid down, and which have escaped being covered up by them or by later strata. Until such prospecting is done on a sufficiently large and efficient scale the opinion, which a few years ago seemed justified, that a mode of occurrence essentially different from the African must be postulated for these countries, should be held in suspense.

The material filling the African pipes shows very pronounced fragmenting and apparently explosive action, which has shattered, and to some extent scattered, the eruptive rock characteristic of both the pipes and the dikes and has mixed it with a very considerable amount of various other rocks, either brought up with it from lower horizons or detached from the surrounding rock masses. Discussion is still going on as to whether the diamonds contained in these agglomeritic pipe-fillings are to be assigned to the eruptive rock proper or to some of the foreign rocks included in it, but the weight of evidence seems to be in favor of the first hypothesis. A very interesting view that was held for many years assigned the formation of the diamond to some kind of reaction *in situ*, between the two classes of rock that occur in the pipes, the necessary carbon being supplied by the carbonaceous rocks through which, in some places, the pipes cut. Subsequent developments have completely disproved this hypothesis, but the essential part of it—the formation of the diamond *in situ*—is still worthy of consideration *if another source of carbon can plausibly be brought into the question.*

So general is the association of the diamond with a fragmental state of the eruptive rock that enters into the composition of the pipes that the question naturally arises whether or not the diamond also occurs in such masses of this rock as have not been subjected to the fragmenting action. From the statements at hand it is clear that there is usually considerable difficulty in distinguishing between the massive and the fragmental forms of kimberlite. Apparently the distinction has only been made in a perfectly conclusive manner by the use of the microscope. The masses that can be thus examined are so small that such negative evidence as they may give has in itself little value. Specimens of diamonds inclosed in fragmental

material are quite common, but thus far those found in which the rock is clearly non-fragmental seem to be exclusively of the type of the so-called "eclogite nodules," which are regarded by some as segregations in the kimberlite magma and by others as transported fragments of a pre-existing rock. In either case the experimental crushing, reported by Mr. Gardner Williams,[1] of 20 tons of these nodules from the Kimberley mine without finding a single diamond, tells strongly against any general hypothesis of genesis based on the sporadic occurrence of these nodules.

In the statements at hand relative to the occurrence of diamonds in the parts of dikes that are not expanded into pipes, the impression is given that the rock is non-fragmental; but the evidence on this point is not as clear as one could wish. As the case stands at present, and until unequivocal evidence to the contrary is presented, there is a reasonable presumption that a positive, perchance a genetic, relation exists between the diamond and the fragmental condition of the rock in which it occurs. This in turn may mean that the origin of the diamond can perhaps be assigned to reactions between the original rock, or rocks, of the filling and other elements whose introduction was made possible by the fragmenting of the mass, and which accompanied, or followed, the explosive action, if, perchance, they did not constitute the actual agency that produced it.

According to ideas generally received among geologists, the explosive action, as such, is but the culmination of previous thermal processes in the sudden production of gases, principally water vapor. The thermal processes may be protracted and varied in action and may occur repeatedly and extend into late phases of the eruptive period and to stages subsequent to it. One of the most important effects of the protracted action would be to saturate the fractured mass of rock with gases and with liquids resulting from their condensation. Various observers have expressed the opinion that this saturation under the conditions implied reached the point of establishing a marked degree of mobility in the mass, converting it into a veritable rock brew. Be this as it may, such a saturation, whatever its degree may have been, would establish conditions in which a certain amount of hydration (serpentinization) of the erup-

[1] *Trans. Am. Inst. Min. Engineers*, 1904.

tive rock, composed largely of olivine, would almost inevitably result.

We thus have in the formative stages of the pipe-fillings (or at least in early stages of their history) a sufficient agency for the hydration of their eruptive portions. Such a change has been observed down to such extraordinary depths that the usual explanation of atmospheric weathering seems utterly incredible.[1] The hydration, which to a greater or less degree seems to be characteristic of all known occurrences of undoubted kimberlite, whether appearing in pipes or dikes, is accompanied by the formation of a certain amount of calcite, which involves the introduction, in some stage of the history of the rock, of carbon in a condition to form the carbonic acid locked up in the mineral. This introduction may also be most plausibly assigned to the stage of thermal agitation, of which the fragmenting and explosive actions were the climax. The analysis cited in the preceding note, representing the least-altered kimberlite thus far examined, gives 2.54 per cent of carbonic acid, corresponding to about 5,000 grams of pure carbon to the unit of volume (load=0.453 cubic meters) used by the African miners in measuring their material. This amount of carbon, if present in the form of diamond, would give about 25,000 carats, whereas the usual yield of the De Beers load is under 1 carat (1/5 gram).

There are thus strong a priori reasons for attributing to deep-seated causes long since extinct a great part of the hydration and carbonation which the eruptive rock, originally free from water carbon, has suffered. If such was the case, it becomes important to distinguish the deep-seated actions from those of the atmosphere, which, acting from above downward, have long been producing similar results. These superficial results would be superimposed on the pre-existing ones, if such existed, down to a certain depth. No question can be raised regarding the correctness of the view,

[1] Dr. Wagner gives an analysis of a specimen of kimberlite collected in the deepest part (2,040 feet from the surface) of the De Beers mine, which had 6.81 per cent of combined water. This, as he expressly states, represents the best-preserved material to be found in the Kimberley group of mines, although in the neighboring Kimberley mine the pipe has been opened up nearly 1,000 feet farther down, or fully 3,000 feet from the surface. From this it may legitimately be inferred that there is little likelihood of finding unhydrated kimberlite in the known South African diamond mines.

very generally received, that atmospheric weathering has transformed the "hard blue" ground into "soft blue," and this in turn into "yellow" ground. If, as here suggested, there had been a previous period in which serpentine and calcite were formed, evidence for or against it should be found in the transition zone between the hard and the soft blue ground. So far as can be gathered from the literature at hand careful search has never been made for such evidence. This seems thus to be one of the crucial points in the study of the genesis of the diamond that is yet to be investigated.

On the assumption that future investigation may establish the deep-seated origin of the alteration of the diamond matrix, a basis is found for submitting to discussion the elements of a new hypothesis regarding the genesis of the diamond. A pipe filled with rock fragments saturated with hot (possibly superheated) gases, and probably also liquids, would constitute an enormous crucible, in which reactions not as yet detected in our laboratories might take place. In this crucible carbon would certainly be present in the form of carbonic acid and probably in other gaseous forms as well. Thus the material and some of the physical conditions for unusual carbon segregation were present, and we are not yet, apparently, in a position to say that a segregation of a minute portion of the carbon into a solid form is a chemical impossibility. It seems to be well established that in certain industrial and experimental processes carbon does separate in the solid form of graphite from carbonaceous gases, and Weinschenk has presented strong evidence in favor of the introduction in a gaseous form of the carbon of the graphite deposits of Bohemia and Bavaria.

From a geological point of view the rôle of carbon in eruptive rocks and in eruptive phenomena generally is as important as it is obscure. It thus presents an attractive subject for experimental researches, such as are contemplated in the program of the Geophysical Laboratory at Washington, which is so admirably equipped both in material and personnel for such investigations. The inquiries in this line thus far reported by various experimenters, while extremely interesting and important in themselves, are unsatisfactory, in so far as they postulate conditions that are with difficulty conceivable in nature.

PRELIMINARY NOTES ON SOME IGNEOUS ROCKS OF JAPAN. IV[1]

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IV. ON LAVA AND ANORTHITE-CRYSTALS ERUPTED FROM THE TARUMAI VOLCANO IN 1909

Introduction.—The volcano Tarumai is located at a distance of about 42 kilometers south of Sapporo, the chief city of Hokkaido. Though the volcano has long been known as one of the active volcanoes in the district, it has become the object of special attention since the outpouring of lava, which took place in April, 1909, forming a dome of 134 meters in height as measured from the neighboring ground, and adding 40 meters to the pre-existing highest peak of the mountain, which is 1,015 meters above the sea-level, according to Ōinoue's report.

A revival of the exhausted volcanic energy, which had remained in the solfataric state since the comparatively great explosion of August 17, 1895, took place at the beginning of the year 1909. After that several outbursts and shocks were reported from the region. At last, in the course of about 24 hours, from the evening of the 17th to that of the 18th of April, lava of about 20,000,000 cubic meters in volume, measured by B. Koto, was poured out of the explosive crater, and a dome was formed which is shown in the accompanying photographs (Figs. 1 and 2).

Reports of the event, written in Japanese by D. Satō and Y. Ōinoue, have been published by the Imperial Geological Survey of Japan and the Earthquake Investigation Committee, respectively. The following brief petrographic description was made by the writer on the specimens collected by D. Satō.

Megascopical characters.—The specimens at hand have in general a glassy and ragged appearance. Those taken from the ejecta are

[1] Published by permission of the Director of the Imperial Geological Survey of Japan.

of light-colored pumice. In their inner part the cellular structure appears well developed, while the outer thin crust is usually glassy and compact, strongly marked by cracks, which are char-

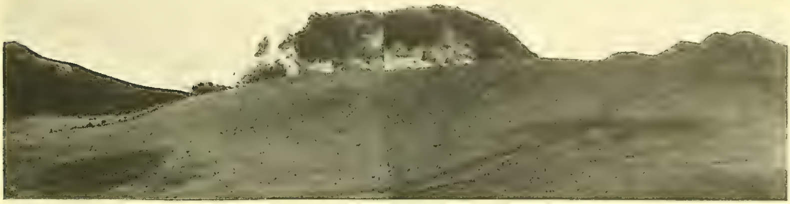

FIG. 1.—View of the new dome from the east, May 11, 1909 (by T. Kawasaki, Imp. Geol. Surv. of Japan).

FIG. 2.—View of the new dome from the southwest, May 11, 1909 (by T. Kawasaki).

acteristic of the so-called bread-crust bombs. This variety contains well-formed anorthite crystals of considerable size, with an average length of 13 mm. Beside these, there are not a few small

megascopic phenocrysts of feldspar and pyroxene, their sizes varying from 1 mm. to 2 mm. The other specimens taken from the new dome are dark gray, or reddish dark gray, in color and spongy or ragged in appearance. Generally, they are characterized by heterogeneity in texture due to their variable crystallinity, and by flow-structure, which is visible in the lava-mass, as shown in Fig. 3.

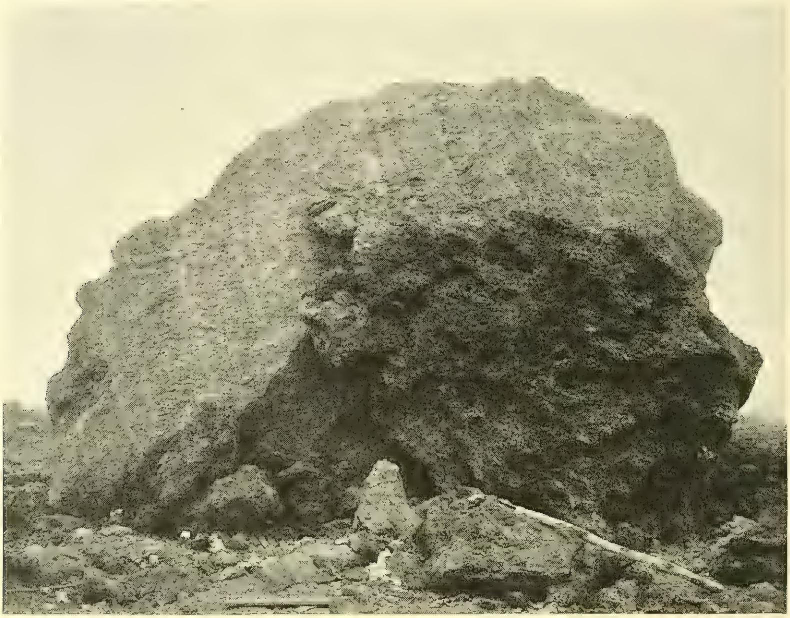

FIG. 3.—Lava-block, showing the marked flow-structure

Sometimes dark-gray to light-gray cryptocrystalline masses are imbedded along the planes of flow in the rock-mass, their shapes being mostly lenticular.

Microscopical characters.—The rock is made up of plagioclase, hypersthene, augite, olivine, magnetite, apatite, and microliths, scattered in the abundant glassy groundmass. The prevailing phenocrysts are of anorthite. Hypersthene comes next, and is nearly equal to, or is more than, the augite. Subhedral magnetite is not rare as phenocrysts. Though olivine appears abundantly associated with the large crystals of anorthite, mostly as peripheral

inclusions, it is rarely met with in the general mass, and may be considered as an accessory constituent of the rock.

The matrix exhibits different textures, according to different conditions under which the lava consolidated. The crustal part of the ejecta is hypohyaline, while its inner part usually shows typical cellular structure, the glass base being colorless. The specimens taken from the dome are more crystalline than those just described, but there is still abundant residual glass. It is moderately clouded with magnetite dust and pyroxene microliths. The megascopically cryptocrystalline part appears holocrystalline under the microscope and consists essentially of granular pyroxene and feldspar, scattered microporphyritically with skeletal crystals of hypersthene.

Feldspar.—The feldspar phenocrysts are of two kinds. One of them is well-formed anorthite of considerable size, 13 mm. in average length. Zonal structure is nearly wanting, or is indistinct. These occur in the ejecta and peripheral part of the lava, or even as isolated crystals, suggesting that their crystallization was prior to that of other minerals. The other variety is smaller in size, with an average length of 2 mm., and is commomly subhedral in shape, sometimes with a strongly curved outline invaded by the glassy groundmass. This variety differs from the first in possessing zonal structure due to variation in the chemical composition and to the arrangement of abundant inclusions. In average composition, the second variety is slightly more sodic than the first. The most abundant inclusions are light-brown or colorless glass with air bubbles in many instances. Apatite and magnetite are also present, commonly in small quantity. In some crystals pyroxene appears as inclusions, but more commonly the feldspar is abundantly inclosed in the hypersthene and augite phenocrysts and shows a distinct automorphic relation toward the pyroxene. The larger crystals will be more fully described in the second part of this article.

Pyroxene.—The hypersthene is easily distinguishable from the augite by marked pleochroism, low double refraction, parallel extinction, and crystal habit. It occurs in crystals of two periods of crystallization. The largest phenocrysts are 2.5 mm. in length

along the axis c. Pleochroism is distinct; α=reddish brown, β=greenish yellow, γ=yellowish green. It is optically negative, the optic plane being parallel to the orthopinacoid. There are abundant inclusions of plagioclase, magnetite, glass, and a few crystals of apatite; of these the plagioclase is large and conspicuous. The smaller hypersthene is rather euhedral in shape and is sometimes marked with transverse cracks perpendicular to the axis c.

Augite crystals are anhedral to subhedral, and also have abundant inclusions, just as the orthorhombic pyroxene. Parallel growth with the hypersthene is common, the hypersthene always being inclosed by augite. Twinning parallel to the orthopinacoidal face commonly occurs, and that parallel to (101) is rare.

Olivine crystals, as already stated, occur in association with the large crystals of anorthite and have well-defined form, elongated along the vertical axis with a length of about 2 mm. The predominating faces, easily identified by the naked eye, are m(110), k(021), and b(010). They are usually coated by a dark-reddish colored, thin crust. They frequently occur in groups of several individuals associated with a smaller quantity of magnetite grains. Notwithstanding the noticeable fact that olivine is nearly absent, or very scarce, in the general mass of the rock, it appears abundantly as peripheral inclusions of the large anorthite.

Magnetite occurs frequently as phenocrysts in association with those of pyroxene, and varies in size from 0.1 mm. to 0.3 mm., in striking contrast with the same mineral in the groundmass, which appears as dusty grains.

Apatite usually occurs as needle-shaped inclusions, but in a few instances larger crystals with a violet color, finely striated parallel to the vertical axis, appear in the groundmass.

Chemical characters.—The analysis of the rock made by N. Yoshioka in the chemical laboratory of the Imperial Geological Survey of Japan is as follows:

SiO_2	60.93
Al_2O_3	16.46
Fe_2O_3	3.35
FeO	5.94
MgO	2.88

CaO	7.84
Na_2O	1.44
K_2O	0.79
H_2O	n.d.
TiO_2	0.42
P_2O_5	0.13
MnO	0.55
	100.78

The norm, calculated from the above figures, is given below:

Quartz	25.1
Orthoclase	5.0
Albite	12.1
Anorthite	36.1
Diopside	2.1
Hypersthene	13.6
Magnetite	4.9
Ilmenite	0.8
	99.7

The ratios are:

$\frac{\text{Sal}}{\text{Fem}}$	3.66
$\frac{Q}{F}$	0.47
$\frac{K_2O'+Na_2O'}{CaO'}$	0.25
$\frac{K_2O'}{Na_2O'}$	0.39

By the Quantitative System the rock would be classified under the name bandose.

In this classification, it may be noted that the rock is characterized by a high percentage of lime, which appears mostly as modal anorthite, and by the comparatively high silica content.

Generally speaking, the mineralogical and chemical characters of the latest lava of Tarumai volcano seem to be representative of

those of the modern pyroxene-andesites, which are widely spread over the Japanese Islands, judging from a cursory glance over the volcanic rocks of Japan. For this reason the name bandose appears to be particularly appropriate.

ANORTHITE-CRYSTALS IN THE LAVA OF 1909

The occurrence of the larger crystals of anorthite is noteworthy. The crystals form large phenocrysts in the lava, and have been

FIG. 4.—Cavity with anorthite crystal. Natural size

ejected separately also as the so-called "anorthite bombs," and are scattered abundantly around the crater; as is the case with the anorthite on Miyake-jima,[1] one of the Seven Izu Islands, Zao-san, a volcano in the province of Rikuzen, and Iwate-san, a volcano in the province of Rikuchu; the oligoclase-andesine[2] on Naka-iō-jima, one of the Sulphur Islands, may be cited as the parallel examples.

[1] Kikuchi, "On Anorthite from Miyake-jima," *Journal of the College of Science, Imp. Univ. Japan*, II, Part I, p. 31.

[2] Wakimizu, "The Ephemeral Volcanic Island in the Iōjima Group (Sulphur Islands)," *Publications of the Earthquake Investigation Committee*, 1908, No. 22 C, Tokyo.

A black, thin coating of lava, which crusts the Miyake-jima anorthite and the Naka-iō-jima oligoclase-andesine, is not seen on the mineral from Tarumai. The crystals, however, have attached to them a small quantity of light-colored pumice. It is evident that the matrix of brittle pumice separated easily from the crystals and that the semi-solidified lava was not so viscous as in the case of the lava of Miyake-jima and of Naka-iō-jima. Also, in some specimens the crystal is in a cavity having well-defined

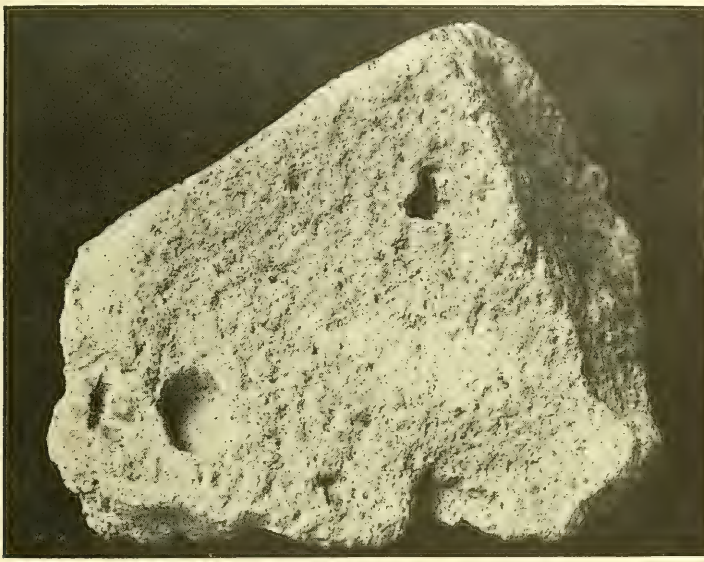

FIG. 5.—Well-defined cavity from which the anorthite crystal has been lost. Natural size.

walls corresponding to the faces of the crystal, with a space about 4 mm. in width between the crystal and the lava. The crystal is attached to the walls by slender, needle-like filaments of glass, as shown in the accompanying photographs (Figs. 4 and 5). There may be several explanations of the formation of these cavities, but the writer believes they were formed chiefly by the differential movements of the crystal and matrix when the blocks of lava were ejected in a semi-solidified state.

The common sizes of the crystals are 10 mm. to 15 mm. in the

longest diameter, though the largest is 20 mm. or longer. Their surfaces are not vitreous, or smooth owing to the presence of pumiceous matrix and inclusions of olivine crystals with a few magnetite grains. The olivine is in well-defined forms, as already described.

The roughness of the crystal faces and the twin striation upon them made the use of the reflection-goniometer very difficult. Even the cleavage piece used for the measurement of the facial angle (001) : (010) did not give a satisfactory result, as the reflection on (010) was disturbed by the pericline twin striations. The angle measured lies between 85° 48′ and 85° 52′. Other approximate facial angles measured by the contact-goniometer are as follows:

l(110) : M(010)	59° 30′
$\bar{y}$($\bar{2}$01) : P(001)	81° 10′
$\bar{y}$($\bar{2}$01) : M(010)	90° 50′
y(201) : *l*(110)	45° 20′
t(201) : P(001)	42°
n(021) : P(001)	46° 40′

From the above angles and the relation of the crystallographic zones the crystal-faces which were identified have been determined as follows:

P(001), M(010), T(1$\bar{1}$0), *l*(110), *t*(201), *y*(20$\bar{1}$), *e*(021), *n*(0$\bar{2}$1), *m*(11), *o*(11$\bar{1}$), *p*(1$\bar{1}\bar{1}$), and *v*(24$\bar{1}$).

The faces P, M, *y*, T, *l*, *o*, *p*, and *n* are always observed, of which P. M, and *y* are the predominating faces. The face *e* is very rare, and *t*, *f*, *v*, and *m* are only found in the tabular crystal parallel to P(001).

Some distinguishable crystal habits are formed by the predominance of different crystal-faces, as given below:

First type: Prismatic, elongated along the axis *a*, with the faces P, M, and *y* predominating, as seen in Fig. 6.

Second type: Tabular, parallel to M, its elongation being along the axis *c*, as seen in Fig. 7.

Third type: Tabular, parallel to P. This type might be subdivided into two varieties, with gradations between them:

a) The elongation is rather along the axis *a* than along the axis *b*, as seen in Fig. 8.

b) The elongation is along the axis *b*, with specially well-developed *y*, as in Fig. 9, finally becoming thick tabular parallel to *y*.

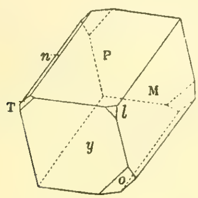

FIG. 6

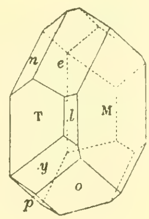

FIG. 7

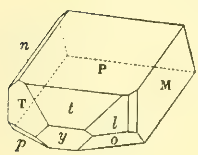

FIG. 8

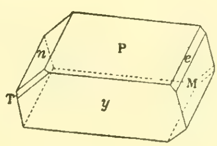

FIG. 9

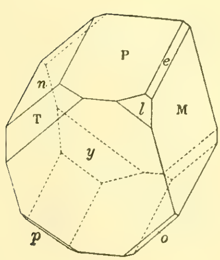

FIG. 10

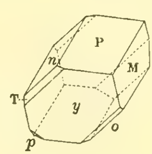

FIG. 11

Fourth type: Cubic, or equant, with comparatively well-developed face *n*. This type might also be subdivided into two varieties, showing gradations into each other or to the first type:

a) With slight elongation along the axis c, as seen in Fig. 10.

b) With slight elongation along the axis a, as seen in Fig. 11.

The prevailing habits are the first and third types; the second and the b type of the fourth are not rare; the a type of the fourth is the scarcest.

Twinning according to the Carlsbad, Manebach, albite, and pericline laws has been observed. There are two or more different types in combination. The albite and pericline types occur polysynthetically, while the Carlsbad type occurs in combination with one or both of these. The Manebach is only found in the tabular crystal parallel to P, mostly combined with pericline twinning. The specific gravity measured by the Westphal's balance in Thoulet's solution is 2.759.

Optical characters.—Extinction angles on P(001) and M(010), measured on cleavage pieces, are $-36° 54'$ and $-35° 24'$, respectively. The measurement of the mean index of refraction was made approximately by means of Wright's solution. The solution corresponding to the mean refraction of the mineral was determined on the Abbe total-reflectometer. The result is $n_y = 1.5785$. The measurement of orientation of the optic axis B was made by the Becke method,[1] with single screw micrometer ocular. The values ρ and r of the axis B were measured on three thin slices parallel to P(001). The results are as follows:

(1) On +P(001)

Micrometer parallel $\begin{cases} \rho = -60° 44.8' \\ r = 0.405 \end{cases}$ Micrometer diagonal $\begin{cases} \rho = +28° 12.6' \\ r = 0.337 \end{cases}$

(2) On +P(001)

Micrometer parallel $\begin{cases} \rho = -60° \\ r = 0.346 \end{cases}$ Micrometer diagonal $\begin{cases} \rho = +25° 5' \\ r = 0.318 \end{cases}$

(3) On −P(00$\bar{1}$)

Micrometer parallel $\begin{cases} \rho = +55° 28.5' \\ r = 0.354 \end{cases}$ Micrometer diagonal $\begin{cases} \rho = -29° 11' \\ r = 0.354 \end{cases}$

[1] Becke, "Bestimmung kalkreicher Plagioklase durch die Interferenzbilder von Zwillingen," *Tschermaks Min. Mitth.*, 1895, Bd. 14, s. 415–42.

From the above figures, the following values for the azimuth of the axis B against the edge P/M on P (ξ) and the true angle-distance (ω) are given:

	ξ	ω
(1)	$-12°$	$19° \ 37'$
(2)	$-12.3°$	$19° \ 14'$
(3)	$-12.7°$	$19° \ 42'$ reduced on +P
	$-12.3°$	$19° \ 31'$

For calculation of ω, $n_y = 1.5785$ and $k = 0.141$ were adopted as the mean index of refraction and Mallard's constant, respectively.

From the mean values of ξ and ω, ϕ and λ were given as follows:

	I	II
$\phi =$	$-0.3°$	$-0° \ 17'$
$\lambda =$	$-5.8°$	$-4° \ 23'$

The values under I are results approximately obtained by the construction of the stereographic projection and those under II by calculation.

Plotting the latter values on Becke's diagram, which indicates the relation between the orientation of the optic axis B of plagioclase and its corresponding chemical composition, the composition of the present mineral would be identified as Ab_4An_{96}—Ab_5An_{95}, as shown in Fig. 12.

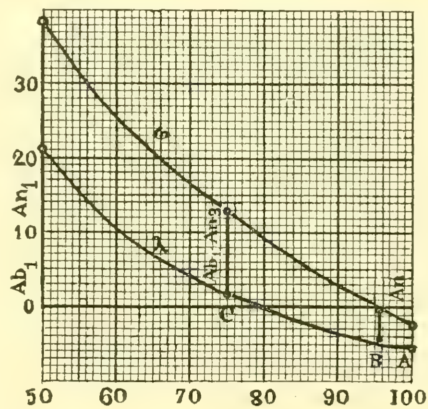

FIG. 12.—In the figure, A is the anorthite from Vesuvius, B is the anorthite from Tarumai, and C is the bytownite from Naeroedal.

The mineral is optically negative with r as the acute bisectrix. The optic angle measured in cedar oil ($n_y = 1.515$) with yellow light, is

$$2H_a = 90° \ 11.5'$$

and its true angle is

$$2V_a = 85° \ 39'$$

Chemical characters.—The mineral is easily attacked by hydrochloric acid, and the powdered sample is readily decomposed with

the separation of gelatinous silica in slightly hot hydrochloric acid of the strength of 22 per cent.

The chemical analysis was made by W. Yasuda in the chemical laboratory of the Imperial Geological Survey of Japan. The sample for the analysis was taken from the clear and fresh part of a crystal, and powdered to grains one millimeter or smaller in diameter. To remove the impure parts, which contained inclusions of olivine, magnetite, and glass, the grains were separated into three portions by Thoulet's solution, having specific gravities of 2.747 and 2.760. The analysis was made of the sample with the specific gravity lying between the two values. The result is as follows:

SiO_2	43.51
Al_2O_3	35.75
FeO	trace
MgO	1.11
CaO	19.48
Na_2O	0.61
K_2O	0.05
	100.53

Subtracting silica and magnesia corresponding to the olivine molecule, and potash as impurity, and calculating the remainder as parts in 100, we have:

	W (percentage)	Mol. prop.
SiO_2	43.30	0.73
Al_2O_3	36.31	0.36
CaO	19.77	0.35
Na_2O	0.62	0.01
	100.00	

From which it is found that the composition of the anorthite may be represented as a mixture of 2Ab and 35An, or $Ab_{5.4}\ An_{94.5}$, which corresponds closely to the value determined optically as $Ab_5\ An_{95}$ $-Ab_4\ An_{96}$.

FACTORS INFLUENCING THE ROUNDING OF SAND GRAINS

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CONTENTS

INTRODUCTION

In 1910, while discussing the rounding of sand grains with Professor A. W. Grabau, it seemed to the author that the influence of viscosity was not sufficiently emphasized in the literature on that subject. Subsequent discussion with Professor C. P. Berkey suggested this investigation. The thanks of the author are due to Professor James F. Kemp, and especially to Professor C. P. Berkey for many kind and valuable suggestions.

THE MOLECULAR FORCES OF LIQUIDS

For a clear understanding of the forces acting on a particle submerged in water it is necessary that we review briefly a few of the elementary definitions of physics. This can most clearly be done by means of an illustration.

If we look carefully at the surface of a glass of water, we notice that it is not horizontal but curves upward at the sides of the containing vessel as though attracted by it. If we dip a clean glass rod in water and remove it, we shall see adhering to it a thin film of water. Upon slightly shaking the rod this film will be dis-

lodged and in falling will assume a more or less spherical form. The smaller the drop, the more perfect its spherical shape. Here we have a homely demonstration of the forces acting on the liquid. The creep-up of the water on the sides of the glass is due to the attraction of the glass for the water; the drop of water remaining on the glass rod is held there by the same force, that is—adhesion. In falling, the water from the rod does not fly off in a series of small particles, but assumes a spherical shape because the component particles of water, or, in other words, its molecules are attracted toward each other. This is cohesion. Adhesion is the attraction of unlike molecules for each other; cohesion is the attraction exhibited between molecules of the same substance.[1] The force due to the cohesion of the molecules of different substances and that due to the adhesion between the molecules of different substances varies. The cohesion of water is less than its adhesion for glass, hence the glass rod is enabled to tear away a certain amount of water.[2] If, however, we dip a glass rod into mercury and withdraw it, nothing will adhere, because, in this case, cohesion is the stronger force.

The space through which cohesion is active is the "sphere of molecular attraction." It is a sphere about 0.00005 mm. in diameter.[3] If we now assume that a liquid is made up of a number of layers of molecules, we will see that the top layer, the free surface, will be attracted unequally because part of its "sphere of molecular attraction" lies outside the liquid.[4]

In Fig. 1 xy is the surface of the liquid. A and B represent two molecules in the surface and beneath the surface respectively.

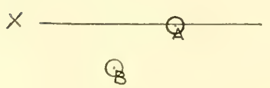

Fig. 1

The circles surrounding them represent the "sphere of molecular attraction." The molecule B is attracted equally in all directions by the molecules falling within its sphere; in the case of the molecule A, however, the attraction will be downward, as the attracting molecules only occupy that part of the sphere lying within

[1] Nichols and Franklin, *Elements of Physics*, 124.

[2] F. Pockels in Winkelman's *Handbuch der Physik*, I, 882.

[3] Duff, *Textbook of Physics*, 146. [4] *Ibid.*, 147.

the water. On this account the surface of the liquid is in a state of tension, and in order to move the molecule *B* to the surface we would have to overcome this force. We may liken the condition of the surface of the liquid to that of the stretched rubber membrane of a ball. We have a pressure at right angles to the surface, capillary pressure, causing a tension parallel to the surface, surface tension.[1]

Let us now consider a grain submerged in a liquid and let us note the action of the different forces upon it. The body will be pulled down by the force of gravity, the magnitude of the pull being determined by the difference in the specific gravity of the solid and the liquid. If we consider water, then the force will be equal to $vg\ (d-1)$; where v is the volume, g the acceleration due to gravity, and d the density of the solid.

In moving through the liquid, the grain will carry down a thin film of water held by adhesion. There is a certain friction developed in this movement which will not be friction between the grain and the water, but friction of water with water. The friction developed by a thin film of water sliding on water is "superficial viscosity." The term "skin friction" is also applied to it.[2] This is the friction especially considered in the flow of water through pipes and conduits. In addition, through the downward movement of the grain, the shape of the liquid is disturbed. Any disturbance or change of shape in a liquid calls forth a resistance, "viscosity." But even if the particle were moving in a "perfect fluid," i.e., a fluid without any viscosity, its energy would gradually be dissipated in forming waves.[3]

To summarize then, a body moving through water must overcome resistance due to three causes; (1) viscosity, (2) skin-friction, and (3) wave-resistance.

If we take a case in which the liquid has a definite velocity, the conditions as outlined above will not change. In this case the grain will be acted on by a force which is the resultant of the velocity and gravity, and will have the direction of the diagonal

[1] Ganot, *Physics*, 122.

[2] Basset, *Elementary Treatise on Hydrodynamics*, 52.

[3] *Ibid.*, 51.

of the parallelogram of forces constructed with velocity and gravity as sides (Fig. 2). The grain will experience no resistance in the direction of the velocity, as it will simply move along with the water. The downward movement will experience the same resistance as though the liquid were at rest.

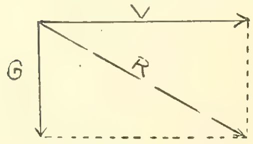

FIG. 2

MOLECULAR FORCES AND TRANSPORTATION

Sediment is transported by water in one of three methods. It is either floated on the surface, or rolled along the bottom, or carried in suspension.

Small grains, when carefully sifted over the surface of water, float, due to the fact that their weight is not sufficient to overcome the surface tension of water. Since surface tension may be defined as the "force tending to make a liquid contract to the smallest area admissible," it will have the tendency to drive the floating grains together.[1] This apparent attraction of grains into patches, although not explained, has been noted by James C. Graham and F. W. Simonds, who described this method of sand-transportation as occurring on the Connecticut and Llanos rivers respectively.[2] Experiments carried on by Simonds seem to show that if the launching be favorable, about 40 per cent of the component grains of most sandstones will float on water. Floating patches of sand and dust have been noticed by the author on the Iowa and Cedar rivers on still days during the summer, where they look essentially like floating patches of scum or foam, and also on the quiet water along the shore of the North Sea, near Otterndorf and Cuxhaven in Germany. While the condition necessary for the transportation by flotation are somewhat unusual, this method still appears to have more importance than is usually attributed to it.

The floating of the grain depends on two molecular forces, viz., cohesion and adhesion. Cohesion causes the tension in the free surface of the water, and resists all attempts to break this surface. Adhesion serves as a modifying factor. If the adhesion

[1] Duff, *op. cit.*, 146.

[2] Graham, *A.J.S.*, series 3, XL, 476; Simonds, *Am. Geol.*, XVII, 29.

between the grain and water be strong enough to wet the grain, it will sink at once; if adhesion be weak, the grain will remain dry and float. The adhesion between the grain and the water may be entirely destroyed by coating them with oil. The so-called "oil-flotation process" of ore dressing depends to a great extent on this principle. The finely pulverized ore is mixed with a small quantity of oil. The metallic sulphides, such as galena, chalcopyrite, and sphalerite, have strong adhesion for oil, and are readily coated, while the quartz and other gangue remain free, unless an excessive amount of oil is used. When the ore is allowed to slide into the settling tanks, the gangue sinks readily, but the coated sulphides float off. Here it seems that molecular forces cause flotation rather than the decrease in specific gravity due to the combined weight of oil and mineral. As the specific gravity of the oil taken is approximately 0.8, in the case of galena the volume of oil to mineral would have to be in the ratio of 32 to 1, to bring the density of the combined material down to that of water.[1]

Sharp, angular grains float more readily than those of spherical shape. This is due to the fact that the force due to the surface tension increases with an increase in the surface area exposed to it. The more nearly spherical a grain, the smaller the ratio between the surface area and the mass of the grain, and hence the greater the ratio of weight to surface tension. Irregularity of shape increases the ratio of surface to mass, and hence decreases the tendency to break through the surface of the film.

The power of water to carry material in suspension depends on a number of factors, some of which are: the shape, size, and composition of the particles; the viscosity, composition, and velocity of the water; the presence of colloids; the character of the river bottom; the course of the stream, etc. The size of grain carried depends directly on the velocity. The more irregular the shape, the greater will be the resistance encountered in settling. The presence of colloidal substances causes rapid settling.[2] Again there may be a change in the composition of the water causing an interaction with the sediment, such as the precipitation of alumina

[1] Adams, *M. and Sc. Press*, May 7, 1904, etc.

[2] F. W. Clarke, *Data of Geochemistry*, 430 (Bull. 330, U.S.G.S.).

by the carbonates of calcium and magnesium, and a consequent settling of the silt.[1] The presence of salts, alkalies, and acids in solution hasten the rate of precipitation. However, Wheeler arrives at the conclusion that there is practically no difference in the rate of settlement of sand and silt in salt and fresh water.[2] When the particles are very fine, as mud and ooze, the rate of settlement is slightly faster in salt than in fresh water. Others have shown that settling is far more rapid in salt than in fresh water, and attribute this fact to a chemical interaction between the salt water and the sediment, carried in this case as a colloid.[3] There is reason to doubt this explanation, and the more rapid settling in salt water seems to be due to a decrease in the viscosity of the water.[4] Rough and irregular river bottoms and swinging meanders tend to keep the water in a stirred condition and hence aid in holding material.

METHODS OF ROUNDING

Sand grains are reduced in size by collision and friction. Hence we know that the wear of a grain depends on a number of factors, such as hardness, weight, distance of travel, cleavage, tenacity, velocity of movement, etc. The rounding of sand grains under the varying conditions has been ably discussed from the geological standpoint by McKee[5] and Goodchild.[6] The movements of solids through fluids have been investigated from the mathematical standpoint especially by Basset[7] and Allen.[8] This feature has also been noted to some extent by Blake,[9] Walther,[10] and Barrell.[11]

[1] E. W. Hilgaard, *A.J.S.*, 1873, p. 288; 1879, p. 205.

[2] W. H. Wheeler, *Nature*, June 20, 1901.

[3] See F. W. Clarke, *Bull. 330, U.S.G.S.*, and H. S. Allen, *Nature*, July 18, 1901, for bibliographies.

[4] J. F. Blake, *Geol. Mag.*, Decade IV, Vol. X, 12; W. B. Scott, *Introduction to Geology*, 141; Carl Barus, *Bull. 36, U.S.G.S.:* Chamberlin and Salisbury, *College Geology*, 316.

[5] McKee, *Edinburgh Geol. Soc.*, VII, 298.

[6] Goodchild, *ibid.*, 208.

[7] Basset, *Elementary Treatise on Hydrodynamics.*

[8] Allen, *Phil. Mag.*, 1900.

[9] Blake, *Geol. Mag.*, Decade IV, Vol. X, 12.

[10] Walther, *Das Gesetz der Wustenbildung.*

[11] Barrell, *Jour. Geol.* (1908), XVI, 159.

Summary of previous work.—McKee in his work evolves the formula

$$R \propto \frac{\text{size} \times \text{specific gravity} \times \text{distance traveled}}{\text{hardness}}$$

where R is the rounding (or the wear).

Considering a cube with the edge x, the distance traveled would be roughly proportionate to the number of times the grain turned over, hence $\frac{D}{4x}$ could be placed instead of distance. The weight of the cube would be x^3 Sp. Gr.

Substituting in the above equation we have

$$R \propto \frac{x^3 \text{ Sp. Gr.} \frac{d}{4x}}{\text{hardness}}$$

reducing to

$$R \propto \frac{x^2 \text{ Sp. Gr. } d}{4h}$$

Or in more general terms—

$$R \propto \frac{x^2 \text{ Sp. Gr. } d}{mh}$$

where m is a constant depending on the shape of the grain. m is 4 in the case of a cube, 3.1416 in the case of a sphere, etc. If the grain is under water allowance must be made and

$$R \propto \frac{x^2 \cdot (\text{Sp. Gr.} - 1) \cdot d}{mh}$$

Goodchild goes farther and determines a general limiting condition to the wear taking place. His work may be summarized as follows:

Since the sand is completely surrounded by a film of the water in which it is submerged, it will be acted on by surface tension. By decreasing the size of a particle we increase the ratio of area to volume, and hence to weight. Since the surface tension of water will act over the area exposed, its magnitude compared to the weight of the grain will increase with decrease in size. Finally, he assumes that a balance between weight and surface tension will be reached, such that no further rupture of the film of water surrounding the grain can take place, and hence all wear will

cease. Thus Goodchild concludes that the factor limiting the amount of wear possible on submerged bodies, is surface tension.

Experimental work.—As stated before, in the movement of bodies through water resistance due to three causes must be

EXPERIMENTS

mm. Diam.	Glycerin	Water	Alcohol
Cassiterite (6.4)*			
3–2	Collision	Collision	Collision
2–1½	Collision	Collision	Collision
1¼–¾	? Repulsion ?	Collision	Collision
ca. ½	Repulsion	? Collision ?	Collision
<½	Repulsion	Repulsion	? Repulsion ?
Chromite (4.5)			
3–2	Repulsion	Collision	Collision
2–1½	Repulsion	? Collision ?	Collision
1–¾	Strong Repulsion	Repulsion	Collision
ca. ½	Strong Repulsion	Repulsion	? Repulsion ?
<½	Strong Repulsion	Repulsion	? Repulsion ?
Quartz (2.65)			
3–2	Collision	Collision	Collision
2–1½	? Repulsion ?	Collision	Collision
1–½	Repulsion	Repulsion	? Repulsion ?
<½	Repulsion	Repulsion	? Repulsion ?
Gypsum (2.35)			
3–2	Collision	Collision	Collision
2–1½	? Repulsion ?	Collision	Collision
1¼–¾	? Repulsion ?	Repulsion	? Collision ?
ca. ½	? Repulsion ?	Repulsion	? Repulsion ?
<½	? Repulsion ?	Repulsion	Repulsion
Anthracite (1.6)			
3–2¼	....	Collision	Collision
2–1½	....	? Collision ?	Collision
1½–1	....	Repulsion	Repulsion
¾–½	....	Repulsion	Repulsion
<½	....	Repulsion	Repulsion

* The figures beside the minerals represent specific gravity.

DATA

	Sp. Gravity	Surf. Tension	Viscosity
Glycerin	1.252	66.5	8.0
Water	1.0	71.	.10
Alcohol	.887	23.4	.011

overcome, viz., viscosity, skin-friction, and wave-resistance. Unless these three factors are overcome, grains cannot collide.

The effect of surface tension, however, is one aiding wear, since it tends to draw grains together in its effort to force the water to assume the least area permissible under the conditions to which it is subject. Thus viscosity, since it is the most potent of the three factors mentioned, limits the minimum size to which wear takes place. The energy of the particle must overcome the viscosity to allow collision. Since the velocity of different grains in water is roughly equivalent, their energy varies directly with the size, the larger grains only having enough power to overcome viscosity. In the case of small grains the water acts as a cushion preventing actual collision, or checking the velocity of contact. To show the action of viscosity in preventing collisions of grains the following experiments were performed.

Grains were dropped down long glass tubes filled with liquids of different viscosities, and the action at the meeting of the grains was observed. Grains of different specific gravities were taken so as to overcome the difference in the specific gravities of the liquids.

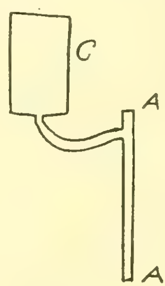

FIG. 3

Again an experiment was performed (Fig. 3) in which the glycerin was allowed to run from the reservoir *C* through the tube *AA* down which the different grains were dropped. The results were practically identical with those above.

It will be noted that the surface tensions of water and glycerin are nearly the same, but that the viscosities are in the ratio of eighty to one. In the case of glycerin it was apparently impossible for the grains of small diameter to collide. Whenever a larger grain would overtake a smaller and slower falling one, there was an apparent repulsion between the two as they were held apart by the viscosity. In small and light grains the repulsion appeared violent so that often a clearing space of a quarter of an inch was shown by grains that apparently were going to collide. As can be seen from the table, in the case of water the protection against collision was much less. Small grains of quartz, less than 1 mm. in diameter showed fairly strong repulsion, but above that size collisions were the rule. Again in the case of alcohol, with a surface tension of

23.4 and a viscosity of 0.011, repulsion was only noticed in the finest grains.

SUMMARY

The results of these experiments seem to show that viscosity is the factor protecting grains from wear. Viscosity will not only prevent the wear of the smaller grains, but it will also act as a buffer and will greatly lessen the velocity of grains when about to collide with each other or with the bottom of the river. In view of the results it seems improbable to the writer that grains less than 0.75 mm. in diameter could be well rounded under water. Well-rounded grains of about this and smaller diameter appear to be the result of wind work, in which case the protecting factor, viscosity, would be practically zero, so that there would be no limit to the minimum size attainable by wear.

THE UNCONFORMITY BETWEEN THE BEDFORD AND BEREA FORMATIONS OF NORTHERN OHIO[1]

WILBUR GREELEY BURROUGHS
Oberlin, Ohio

In Lorain County of northern Ohio, 30 to 40 miles west of Cleveland, occurs a striking unconformity between the Bedford and Berea formations. In Ohio the Bedford formation is the lowest member of the Waverly group, Mississippian system. It is an argillaceous shale, the lower portion being a dark bluish gray, the upper portion a chocolate or dark red color. The Berea formation above is a bluish-gray, fine-grained sandstone.

STRUCTURE OF THE BEDFORD AND BEREA FORMATIONS

Dynamic movements of the region have taken place since the laying-down of the Berea sandstone, both formations being uniformly folded. The general structure is that of a syncline whose axis runs northeast and southwest. The red Bedford shale comes to the surface on either side of this trough, which averages about two miles in width. A great deal of the sandstone in the syncline itself has been eroded away, exposing the red Bedford shale beneath. The large rock trough contains minor anticlines and synclines, with axes parallel to that of the large syncline. A compressional force from the east and west has folded the axis of the northeast-southwest syncline into a series of anticlines and synclines. At South Amherst, in the region under discussion, the axis of the large syncline is plunging toward the east.

LENSES OF BEREA SANDSTONE IN THE HORIZON OF THE BEDFORD SHALE

The Bedford forms steep banks where the streams cut against it. As one goes along Beaver Creek, which flows just east of the

[1] The writer wishes to thank Professor G. D. Hubbard, of Oberlin College, for criticism of the manuscript. The work was done in the Department of Geology at Oberlin College.

Berea sandstone quarries at South Amherst, or Chance Creek on the west, he will occasionally find the high banks covered by a mass of Berea sandstone talus. This débris came from a lens of sandstone *in situ* at the top of the bank, extending for 50 to 100 feet on the horizontal, and flanked on either side by red Bedford shale. In places the sandstone is in thin beds 2 to 3 inches thick, at other places in massive beds 3 to 4 feet thick. The lenses range from 10 to 50 feet in total thickness. Their long axes run in a general westward direction. No evidence of slumping is found in connection with the banks at and in the vicinity of these lenses. Neither can they be the bottom of synclinal troughs, for the dips of their minor axes are not great enough to bring the sandstone to the top of the bank of Bedford shale. The only answer to the question of their origin is that there were once channels and depressions in the Bedford shale which, on being filled with sand, ultimately formed (in cross-section) the lenses as they now exist.

So far as the writer is aware, nothing has ever been published regarding this unconformity between the Bedford and Berea formations of northern Ohio, save in the *Ohio Geological Survey Report*, Vol. II, published in 1874. This report mentions lenses in the horizon of the Bedford shale north of Elyria, which is to the eastward of the region under discussion in this article. On p. 91 we read, referring to the erosion of the Bedford prior to the deposition of the Berea: "It is probably due to this fact that the red shale is so frequently found to be wanting in the section."

Mr. H. E. Adams, superintendent of the Ohio quarry at South Amherst, Ohio, states that in the extreme southeast corner of Lorain County, Berea grit occurs in lenses in the horizon of the red Bedford shale exactly in the same manner as at South Amherst.

The Bedford-Berea unconformity is not confined to Lorain County, Ohio. Dr. Hubbard is authority for the statements that "an unconformity occurs at the same horizon in northwestern Fairfield County near Lithopolis; and Professor Prosser believes a similar break exists at the same horizon near Cleveland, Ohio, but further work is there necessary."

The sand-filled troughs in the erosion plane of the Bedford formation which are visible along the streams are small and insig-

nificant in comparison with the channels and valleys whose existence is made known by the drill of the quarry-men.

The deepest of these sand-filled depressions is that in which is located the quarry of the Ohio Stone Company (Fig. 1). This quarry is situated on the outskirts of South Amherst, Lorain

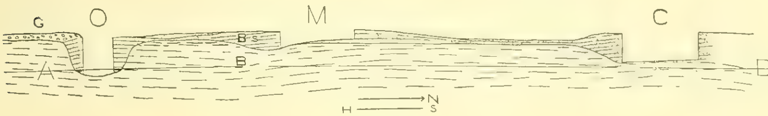

Fig. 1

Horizontal and vertical scale - - - - line *H–S* = 400 feet. - - - - *N* = North. Line *A–D* = elevation of 600 feet above sea-level. *B* = Bedford shale. *Bs* = Berea sandstone. *G* = glacial drift. *O* = Ohio quarry. *M* = Malone quarry. *C* = No. 6 quarry, Cleveland Stone Co.

County, Ohio. The pit has been sunk along the axis of an anticlinal fold which runs in a southwesterly direction. The anticline plunges eastward with a dip of 3°. The south flank of the fold in the quarry has a dip of 6° to the southeast; the north side dips 7° northwest. The great thickness of the sandstone, 217 feet, is due to the sand-filled channel of the eroded Bedford horizon. That this is true is shown by drillings and the structure of the strata in the vicinity. One hundred feet southwest of the edge of the quarry on the same level as the top of the quarry pit, the drill went 60 feet thorugh glacial drift and came upon Bedford shale without encountering any sandstone, and yet the strata in the pit were dipping in that general direction. In the quarry 217 feet of sandstone were passed through before striking Bedford shale. Four hundred feet on the horizontal from the north side of the quarry the strata dip toward the southeast. One thousand feet on the horizontal from this north side of the Ohio quarry, and on the same level as the top of the quarry, another quarry, the Malone, has gone down 100 feet through massive sandstone to the Bedford shale. Here the strata still dip to the southeast; the dip is 7°. Thus a small syncline lies between these two quarries. The dips of the strata are not great enough to carry the sandstone to the depth reached in the Ohio quarry even though the syncline did not exist.

Therefore the Ohio quarry is located in a depression of the eroded horizon of the Bedford shale. The Ohio pit is 175 feet wide, yet neither bank of the Bedford channel in the quarry has been reached.

By drill and well records, the writer has traced this channel, in which is the Ohio quarry, for a distance of three and one-half miles to the southwestward where it outcrops on the steep valley slopes of a stream known as Chance Creek. Here the lens of sandstone is 50 feet wide and 15 feet thick. On both sides and at the bottom the sandstone lies directly against the red Bedford shale. The decreasing of the channel in depth and width as it went southwestward indicates that the stream flowed from the southwest toward the east.

Beaver Creek flows a little less than one-half mile east of the Malone quarry. Here no sandstone is found along the banks, in spite of the fact that the axis of the anticline is plunging in that direction at an angle of 3°. The outcrops of Bedford shale at this place on the creek are 30 to 40 feet lower in elevation than the top of the sandstone at the Malone quarry, where the sandstone is 100 feet thick. Still, if the Malone quarry deposit of Berea grit is not a sandstone-filled depression in the Bedford shale, the sandstone should outcrop at Beaver Creek, which it does not do. This quarry therefore also is located in a lens of sandstone in the horizon of the Bedford shale.

A short distance farther north of the Malone quarry is No. 6 quarry of the Cleveland Stone Company. Structurally this quarry is on the southward-dipping flank of an anticline whose axis runs in a southwesterly direction. The average dip is 8°. The axis itself is folded into a low, small anticline in the west portion of the quarry. Here, as elsewhere in the region, the sudden great thickness of sandstone cannot be accounted for save as a sand-filled channel of the eroded horizon of the Bedford shale. Although the long axis of No. 6 quarry does not exactly coincide with the direction of the channel in which it is located, yet, both being in nearly the same westerly direction, the size of the pit gives some idea as to the size of the valley in the Bedford formation. The quarry is 2,632 feet long, has an average width of 460 feet, and a depth of from 100 to 175 feet.

BLUE SHALE AT THE UNCONFORMITY

In the bottom of all these deep channels in the horizon of the red Bedford shale is a soft, dark-blue shale, three to four feet thick. This blue shale is not found beneath the sandstone of the small lenses in the Bedford horizon, nor is it found at any given horizon. The bottoms of the quarries are at different depths with the dip of the strata too slight to bring this blue shale to all the quarry floors. The outcrop of the Ohio quarry channel on Chance Creek had no blue shale beneath the sandstone, the sandstone resting directly upon red Bedford shale. Yet this blue shale is found underlying the sandstone in the Ohio pit.

The reason for the location of this blue shale may be the following: The lower and deeper portions of the valleys of the Bedford streams became drowned. Sediment carried by the rivers into these quiet bodies of water was deposited and eventually formed this blue shale which occurs between the red Bedford shale and the Berea sandstone.

Dr. Hubbard and the writer made a careful search for fossils in this blue shale, but none were found.

CONCLUSION

Starting a few miles east of Sandusky, Ohio, and extending eastward to Cleveland, Ohio, there is a well-defined unconformity between the Bedford and Berea formations. The unconformity, however, extends over a greater area than the region above defined, as it has been noted as far south as Fairfield County, Ohio.

During the period that the Bedford horizon was above the level of the sea, its surface was dissected, streams cutting deep channels and wide valleys. The lower portions of these valleys became drowned. In the quiet water thus formed, the rivers deposited sediment which later became a blue shale, logically belonging to the Berea formation.

The entire Bedford land area gradually was submerged, and the Berea sandstone formation was laid down.

EDITORIAL

In recent years there has been a notable increase in the desire for the use of photographic illustrations on the part of authors of articles submitted to the *Journal*. To an increasing extent such use is coming to be more than a merely helpful or ornamental accessory; it is often an essential means to an adequate presentation of results. In a like manner there has been a marked growth in the use of maps, sections, diagrams, and other graphic matter, as also of analyses, computations, statistics, and similar matter assembled in tabular and diagrammatic forms. It seems inevitable that the proportion of these classes of relatively expensive matter will continue to become greater. To this imperative increase in the expense of properly illustrating the matter of the *Journal*, there is added the greater cost of printing and publishing resulting from the general advance in prices. To meet the demands of these changed conditions, it has been decided to raise the price of the *Journal* to subscribers, beginning with the twentieth volume, except that current subscribers may renew their subscriptions for one year at the present rate if they do so previous to July 1, 1912. Details may be found in the Publishers' notice in the advertising section of this issue.

T. C. C.

Reviews

Ueber Erythrosuchus, Vertreter der neuen Reptilordnung Pelycosimia. By F. von Huene. Geologische und paleontologische Abhandlungen, X (1911). Pp. 58; plates 11.

The genus *Erythrosuchus* was described five years ago by Dr. R. Broom, from the Triassic of South Africa; it was referred by him to the Phytosauria, from which it differs especially in having terminal nares and short premaxillae. Dr. Heune, after a careful study of the known remains of the genus, reaches, in the above-cited paper, the startling conclusion that the genus represents a new order of reptiles allied to the Pelycosauria; that is, that it is a branch from the root-stem of that group ("Zweig von der Wurzel der Pelycosaurien"). Aside from the differential characters already mentioned, *Erythrosuchus* differs from the phytosaurs chiefly in the structure of the limbs, which seem to resemble more those of the pelycosaurs and other primitive reptiles. The skull, as Huene admits, has "viele und auffallende Übereinstimmungen mit den Phytosaurien," in its two temporal vacuities, the absence of additional temporal bones, antorbital vacuities, etc. The vertebrae also, are of the archosaurian type, differing especially from those of the Pelycosauria in the shallow concavities of their centra, the absence of intercentra, and especially in the articulation of the dorsal ribs. It is an important fact, which the author does not seem to appreciate, that the mode of rib articulation is highly characteristic of the reptilian orders. It may be set down as a fundamental taxonomic principle that no related groups of reptiles, or other vertebrates differ materially in the way in which the dorsal ribs articulate with their vertebrae. All the archosaurian reptiles are alike in this respect—double-headed ribs articulating with the diapophyses of the arches exclusively, at least posteriorly—a character found in no other vertebrates. And this is the condition in *Erythrosuchus*, a character in itself sufficient to fix its position among the Archosauria, and by Archosauria I mean the Crocodilia, Dinosauria, Pterosauria, and Parasuchia. The Sauropterygia, it is true, also have the dorsal ribs attached exclusively to the diapophyses, but the ribs show no division into capitulum and tuberculum, differentiating the order sharply. Under the Sauropterygia I include only the Nothodontia and Plesiosauria—the Mesosauria, which are sometimes included in the order,

belong, I am satisfied, with the Theromorpha. The Pelycosauria, like other primitive reptiles, have the ribs attached invariably to the intercentral space and the diapophysis; that is, they are double-headed throughout, while the Cotylosauria, with like attachments, may have the articulation continuous from head to tubercle.

In the pectoral girdle about all the difference that *Erythrosuchus* presents from the phytosaurs is a distinct supracoracoid foramen—precisely the character that would be expected in the more primitive form; and the pelvis, while agreeing in the main with the phytosaurs, differs very materially from that of the pelycosaurs. The chief differences that the author finds allying the genus to the pelycosaurs, are, as stated, found in the limbs: "*Erythrosuchus* kann, trotz der vielen Ähnlichkeit überhaupt, kein Parasuchien sein, da das Femur besonders in der Bildung des Proximalendes mit den primitiven und älteren Pelycosaurien und Cotylosaurien . . . . völlig übereinstimmt." Admitting this "complete agreement" of the proximal end of the femur between *Erythrosuchus* and the Pelycosauria and Cotylosauria, can one not conceive that the resemblances have been brought about by adaptation to like conditions, that the characters are adaptive and not genetic here, as so often elsewhere? But I do not admit this complete agreement. There is much variation in the femora of the cotylosaurs and pelycosaurs, as witness those of *Dimetrodon*, *Araeoscelis*, *Diadectes*, *Seymouria*, and *Labidosaurus*. The humerus of *Erythrosuchus*, although it has a large lateral process and greatly expanded ends, differs materially from that of the pelycosaurs and cotylosaurs in the absence of the entocondylar foramen. One does not refer the moles to a distinct order of mammals because of the differences in the humeri from other rodents.

The skull structure of *Erythrosuchus*, with its upper temporal and antorbital vacuities, is so much at variance with the theromorph reptiles, that I can see no possible evidence of genetic relationships between them. Unless Huene would make the Archosauria a part of the same branch, from the root of the Pelycosauria, he attempts to prove too much, for he would make the Pelycosimia a distinct branch or phylum of the reptilia and entitled to more than ordinal distinction. He classes the Pelycosauria with the single-arched reptiles and is correct in so doing, but I confess I am not quite clear as to the real distinctions between upper and lower temporal vacuities in such reptiles. Nor does Huene seem to be either, as witness the following quotations:

Op. cit. page 41, second paragraph: "Da bei *Deuterosaurus* das

Postorbitale den unteren Rand der einzigen Schläfenöffnung begrenzt, ist sie als die oberen aufzufassen, und sie sind, im Gegensatz zu den ebenfalls monozygocrotaphen Pelycosaurien und Therapsida als 'hypozygocrotaphen' zu bezeichnen."

Same page, fourth paragraph: "Alle Therapsida (mit warscheinlicher Ausnahme von *Cynognathus*) besitzen bekanntlich nur eine einzige Schläfenöffnung, *die der oberen entspricht* (italics mine). Darin und in der Forme des Quadratums stimmen sie alle mit den Deuterosaurien," etc.

Page 43, second paragraph: "Da die untere Schläfenöffnung nicht entwickelt, resp. nach unten nicht geschlossen ist, fehlt den Therapsiden das Quadratojugale," etc.

Same page, third paragraph: "Da bei den Therapsiden das Postorbitale und Postfrontale an der oberen Ecke der Schläfenöffnung liegen, ist letztere als untere Schläfenöffnung aufzufassen, die Therapsiden sind also katazygocrotaph."

From personal conversation with Dr. Huene I know that the last statement expresses his real views; but nevertheless the flat contradictions on these two pages indicate an unsettled opinion. As I have already stated (*American Permian Vertebrates*, p. 92) Broom has figured *Tapinocephalus* with the postorbital and squamosal in broad contact, but he nevertheless holds that the vacuity above them is the "lower" one. One must therefore wait for further light on the subject before accepting their views.

And there is much confusion also about the quadratojugal bone. It is known to occur in only one genus of the Therapsida, *Dinocephalus*, but both Broom and Huene insist that it is present in the Pelycosauria, and Broom has figured it in *Dimetrodon*. But, a study of the material in the University of Chicago—material in which this region is preserved most perfectly—enables me to say positively that there is no such suture or foramen in the lower arch as Broom gives. That a very small, vestigial quadratojugal bone may occur at the extreme posterior end of the jugal is possible, but I have never seen any satisfactory evidence of it, and I doubt its presence, as does also Professor Case.

In brief my own opinion is that Broom was quite right when he referred *Erythrosuchus* to the Phytosauria, using the term in a wide sense as a synonym of Parasuchia. In any event *Erythrosuchus* is an archosaurian reptile with no direct affinities with the Pelycosauria.

In expressing these differences of opinion I would in no wise deprecate the value of Dr. Huene's paper. It is a useful one and may be perused with profit.

In conclusion I wish to protest against the restoration Huene has made of my figure of the pelvis of *Eubrachiosaurus* Will. (p. 49). The outlines as I gave them are essentially correct, and the bones do *not* belong on the right side. As to the distinction of the genus from *Placerias* Lucas, I am, however, not so sure.

S. W. Williston

The Monroe Formation of Southern Michigan and Adjoining Regions. By A. W. Grabau and W. H. Sherzer. [Michigan Geological and Biological Survey. Publication 2. Geological Series 1.]

This report describes a series of Paleozoic beds and their faunas which have their greatest development in southeastern Michigan and the adjacent portions of Ontario and Ohio. In the past these strata, which constitute the Monroe formation, have been much misunderstood, and their importance in the Paleozoic section of the region has been greatly underestimated. The maximum thickness of the formation is about 1,200 feet.

The Monroe as a whole is divided into two series of dolomitic beds, the Lower and Upper Monroe, separated by the Sylvania sandstones, a bed of exceptionally pure, white, and almost incoherent sand in its more typical development, but merging into arenaceous dolomites in its less typical expression. The maximum thickness of the Sylvania is 300 feet, and the peculiar nature of the formation is explained on the hypothesis that it is an aeolian deposit laid down under essentially desert conditions, the original source of the material being the exposures of the Saint Peter sandstone to the northwest in Wisconsin.

The Monroe faunas are described in detail and are illustrated by twenty-five plates; 126 species in all are defined, many of them new forms, and seven new genera are proposed. The faunas of the two divisions of the Monroe are shown to be essentially different, there being almost no species in common. The Lower Monroe faunas are all late Silurian in aspect, being more or less closely related to the Manilus and Rondout formations of eastern New York. In the lower divisions of the Upper Monroe a conspicuous coral element appears which was entirely lacking in the Lower Monroe faunas, and among these corals are many strikingly Devonian forms; among the brachiopods are found both Devonian and Silurian types; the pelecypods are Devonian while the gastropods and cephalopods are essentially Silurian in aspect.

Lying above the beds carrying the strikingly Devonian fauna of the Upper Monroe, is the Lucas dolomite, the youngest member of the series, in which the fauna is Silurian in aspect throughout.

In their correlation of the Monroe series the authors adopt a new arrangement of the North American Silurian formations, as follows: (1) Lower Silurian or Niagaran, (2) Middle Silurian or Salinan, (3) Upper Silurian of Monroan. The Lower Monroe is said to be unrepresented in either western or eastern New York, but is correlated with the so-called "Salina" and the lower portion of the Corrigan formation of Maryland. The lower portion of the Upper Monroe is correlated with the Bertie waterlime and Akron dolomite of western New York, and with the Rosendale waterlime and Cobleskill of eastern New York. An equivalent of the Lucas dolomite is wanting in western New York but it is represented by the Rondout and Manlius of eastern New York and by the Corrigan formation of Maryland.

In a discussion of the paleogeography of Monroe times it is suggested that the faunas of Silurian aspect in the Lower Monroe and in the Lucas dolomite have had an Atlantic origin, while the faunas with the notable Devonian expression in the Upper Monroe below the Lucas dolomite have come in from the north.

S. W.

The Fossils and Stratigraphy of the Middle Devonic of Wisconsin. By Herdman F. Cleland. [Wisconsin Geological and Natural History Survey, Bulletin No. XXI.]

The Devonian faunas occurring in the neighborhood of Milwaukee and Lake Church, Wisconsin, are of especial interest to students of Paleozoic historical geology because of their intermediate geographic position between the much better known Devonian faunas of New York and of Iowa. The present report by Dr. Cleland records a complete census of these faunas with detailed descriptions of the species, accompanied by fifty-three plates of illustrations. Something over 200 species are recognized. Of the total number of species 81 occur in Devonian faunas east of Wisconsin, mostly in New York, while 48 species occur in the Devonian of Iowa and other localities to the west. This mingling of the eastern and western faunas of late Middle and early Upper Devonian time in the Milwaukee region has been pointed out before, but here for the first time do we have a full statement of the evidence.

S. W.

Yorkshire Type Ammonites. Part III. Edited by S. S. Buckman.

The scope of this work has been defined in a notice of the earlier parts. The present instalment includes the original descriptions with additional notes by the editor, and figures of the type specimens, of eight species, bringing the total number of species now defined and illustrated up to thirty.

S. W.

Report on Traverse through the Southern Part of the Northwest Territories from La Seul to Cat Lake in 1902. By Alfred G. Wilson. [Geol. Survey of Canada, No. 1006.] Pp. 21.

The district traversed was wholly an area of Archaean rock (schists and granites). Many of the granites were notable on account of the large amount of microcline contained. Schists were mainly basic, biotite, and amphibole schists. Glacial striae indicated a general glacial movement S.W. to W.S.W.

H. C. C.

Oil Resources of Illinois with Special Reference to the Area Outside of the Southeastern Fields. By Raymond S. Blatchley. [Bull. Illinois State Geological Survey No. 16, pp. 7–138]; Plates 13, Figs. 2.

In this report the author presents a general review of the geology of Illinois as applied to the petroleum industry. He tabulates and represents graphically a number of well records which are chosen to furnish a series of sections running in different directions across the central and southern part of the state. The No. 6 coal bed furnishes a key horizon, the underlying formations lying generally parallel with it. In a few of the better-explored areas this horizon is mapped in contour.

E. R. L.

Meteor Crater (Formerly Called Coon Mountain or Coon Butte) in Northern Central Arizona. By D. M. Barringer. Read before the National Academy of Sciences at Its Autumn Meeting at Princeton University, November 16, 1909. Pp. 24; Plates 18, Maps 3.

There seems to be no doubt that the so-called crater is the work of a falling meteorite. The author has made a careful and detailed

study of the whole region and finds abundant evidence which renders any other hypothesis untenable. The question as to what has become of the projectile still remains unsettled. There are three possibilities: (1) that it was broken into many small pieces and thrown out of the crater; (2) that it has disappeared within the crater through oxidation or some other cause; (3) that it is still somewhere in some form in the depths of the crater. The author concludes that the last is the true explanation and that the remains of the meteorite may yet be found.

E. R. L.

Age and Relations of the Little Falls Dolomite (Calciferous) of the Mohawk Valley. By E. O. ULRICH AND H. P. CUSHING. [N.Y. State Museum Bulletin 140, Sixth Report of the Director 1909, pp. 97–140.]

To clear up some uncertainty as to the exact stratigraphic relationships of the Little Falls Dolomite, a series of sections in the Mohawk Valley were studied by the authors and described and correlated in detail. The formation was found to be in conformable sequence with the Theresa formation and the Potsdam sandstone below and separated by an unconformity from Beekmantown beds above. The paper concludes with a strong argument for the adoption of the proposed Ozarkian system of which the Little Falls Dolomite is a member.

E. R. L.

Report of the Vermont State Geologist, 1909–1910. By G. H. PERKINS AND OTHERS. Pp. 361; Plates 71, Figs. 31.

The report contains the following papers: "History and Condition of the State Cabinet," by G. H. Perkins, pp. 1–75; "The Granites of Vermont," by T. N. Dale, pp. 77–197; "The Surficial Geology of the Champlain Basin," by C. H. Hitchcock, pp. 199–212; "Trilobites of the Chazy of the Champlain Valley," by P. E. Raymond, pp. 213–28; "Geology of the Burlington Quadrangle," by G. H. Perkins, pp. 249–56; "Preliminary Report on the Geology of Addison County," by H. M. Seely, pp. 257–313; "Asbestos in Vermont," by C. H. Richardson, pp. 315–30; "Mineral Resources," by G. H. Perkins, pp. 331–52.

Eight plates illustrate the trilobites of the Chazy and ten the fauna of the Fort Cassin beds (Beekmantown) which are found in Addison County.

E. R. L.

Iowa Geological Survey, Vol. XX. Annual Report, 1909, with Accompanying Papers. By SAMUEL CALVIN, State Geologist, and Others. Pp. 542; Plates 42, Maps 10, Figs. 42.

The report contains the following papers: "Geology of Butler County," by Melvin F. Arey, pp. 1–60; "Geology of Grundy County," by Melvin F. Arey, pp. 60–96; "Geology of Hamilton and Wright Counties," by Thomas H. MacBride, pp. 97–150; "Geology of Iowa County," by S. W. Stookey, pp. 151–98; "Geology of Wayne County," by Melvin F. Arey, pp. 199–236; "Geology of Poweshiek County," by S. W. Stookey, pp. 236–70; "Geology of Harrison and Monona Counties," by B. Shimek, pp. 271–486; "Geology of Davis County," by Melvin F. Arey, pp. 487–524.

Shimek's report on the geology of Harrison and Monona counties contains a detailed description of the mammalian fauna recently discovered in the Aftonian interglacial deposits. These are especially important, since in only one other instance in North America has it been possible to determine definitely the age of a Pleistocene mammalian fauna. Preliminary reports and descriptions of this fauna have been published by Shimek and by Calvin in *Science* and in the *Bulletins of the Geological Society of America.*

E. R. L.

Practical Mineralogy Simplified. For Mining Students, Miners, and Prospectors. By JESSE PERRY ROWE. New York: John Wiley & Sons, 1911. Pp. 162.

This textbook is arranged to give a few special or characteristic properties or tests for the common minerals, that will enable persons unskilled in chemistry or mineralogy to identify them by simple methods. It is readable and well arranged. It will doubtless serve a useful purpose.

W. H. E.

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THE BEARINGS OF RADIOACTIVITY ON GEOLOGY

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To the geologist the center of interest in the phenomena of radioactivity lies in the spontaneous evolution of heat attending atomic disintegration. This interest is the more piquant because the source of the internal heat of the earth is one of the oldest of its problems and the discovery of radioactivity brings into the study an unexpected element. During the last century there was a rather general consensus of opinion that the earth's internal heat was derived from the condensation of the nebula from which the earth was then commonly supposed to have taken its origin. This nebula was usually regarded either as a gaseous body or as a quasi-gaseous meteoritic swarm, and in either case its condensation was thought to have given rise to intense heat. The primitive gaseous or quasi-gaseous earth-mass was held to have passed later into a molten globe, and the subsequent incrusting of this to have entrapped in the interior the heat supply of subsequent ages. This older view was still in general possession of the field when the apparition of radioactivity forced a new line of thought. But there was also an alternative view built on the belief that the earth grew up gradually by the slow accession of discrete orbital matter in distinction from the direct condensation of a gaseous or quasi-gaseous mass. In this view, the internal heat arose mainly from the self-compression of the earth-mass as it grew.

This view had its origin in the grave cosmogonic difficulties that had been discovered in the gaseous and quasi-gaseous theories of the earth's origin. Of the two rival views thus already in the field, the one postulated a plethora of heat at the outset and a gradual loss in all later time, the other postulated at the outset a more limited supply of heat which was increased as compression progressed. The adequacy of such compression to give a sufficiency of heat was a subject of debate from the inception of the view.[1] To the interest that naturally attaches to the discovery of a wholly unexpected agency, already acute because of the agent's singular qualities, there was thus added piquancy in view of its inevitable bearings on the thermal problem of the earth's interior and on the hypotheses of the earth's origin.

An even more fundamental though less imminent interest was awakened by the discovery that some of the atoms of the earth-substance are undergoing spontaneous disintegration and that all atoms may possibly be doing so and that even the permanency of terrestrial substance may be brought into question. However, matters of this ultra-radical nature cannot be discussed with advantage as yet, for little light has been shed on the broad question whether all terrestrial substance is in process of disintegration, and on the complementary question whether atoms are somewhere and somehow undergoing integration.

If the general tenor of the studies thus far made is to be trusted, nothing in the field of common experience seriously inhibits the dissolution of the radioactive substances. It does not appear that even the greatest heightening or lowering of temperature or pressure that can be brought to bear either stays or hastens, in any material measure, the progress of atomic disintegration. Nor do any known changes of chemical union or disunion, of concentration or diffusion, or of freedom or confinement seem materially to retard or accelerate the spontaneous dissolution. There is probably no warrant for an unqualified affirmation that neither temperature, pressure, concentration, exposure, nor combination

[1] The status of the problem of the earth's heat as it stood near the opening of the twentieth century is sketched more fully in *Year Book No. 2*, Carnegie Institution, 1903, 262–65, and in *Geology*, Chamberlin and Salisbury, I (1904), 533–47.

affects the progress of radioactive decomposition, but no specific effects of a critical value have been certainly disclosed by experimentation. These conditions that so much qualify most geologic processes must apparently be regarded as negligible for the present so far as radioactivity in the earth's crust is concerned. It is thought by the leaders in radioactive science permissible to treat radioactive substances as undergoing disintegration persistently and uniformly under all known terrestrial conditions. In the thermal problem of the earth radioactive particles may be dealt with tentatively as centers of heat-generation whose efficiency and endurance are conditioned simply by their atomic constitutions and their mass values. In so far as these remarkable deductions from experimentation may be thought to fall short of full warrant, weakness in equal degree must of course be held to enter into the geological inferences based on them; and in view of the radical nature of the conclusions to which they lead, we cannot perhaps too constantly bear in mind that the postulate of immunity to conditions is the main basis of the geologic contributions credited to radioactivity. But the remarkable verifications of skill and accuracy that have followed the multiplication of tests furnish an ample warrant for a serious discussion of present deductions. There is strong presumption that future tests will further substantiate present conclusions so far as their main bearings on immediate terrestrial problems are concerned, whatever interrogations one may be disposed to indulge in regarding ulterior problems.

The clue to this extraordinary tenacity of radioactive dissolution in spite of conditions that profoundly influence most terrestrial processes, probably lies in the fact that the action springs from the internal motions of the atomic constituents and that these are of such intense nature and are actuated by such prodigious energies that the influences of ordinary chemical and physical conditions are relatively insignificant.

At the same time, the radioactive substances show a decided aptitude to enter into chemical combination under common conditions. None of the parent radioactive metals is known to occur in the earth in a native state. In the form of compounds they have become widely distributed over the face of the globe in the

course of the surface changes it has undergone. Radioactive substances have freely entered into solution in the natural waters and have thus been carried wherever the hydrosphere reaches, and in turn they have been deposited therefrom. Their singular property of passing spontaneously from certain states into gaseous forms (emanations) and then back into the solid or liquid form, on definite time schedules, has caused them to be given forth freely into the atmosphere, and, drifting in this, to be later precipitated in the solid or liquid form, and this has naturally been dispersive in an extreme degree. Radioactive matter is therefore found in practically all the rocks of the surface of the earth, in practically all the waters, and in practically all the atmosphere.

But this highly diffusive distribution has not been uniform. There have been special tendencies toward concentration running hand in hand with the general tendencies to diffusion, and these concentrative tendencies constitute a critical element in this discussion.

So far as the accessible part of the earth is concerned, the igneous rocks may be taken as the original source of the radioactive substances. How the igneous rocks themselves came to have their present content will be considered later. Whence the radioactive substances came still more remotely is problematical. There may be even now accessions of radioactive substances from without the earth for aught that is known, and indeed this is probable; but, except in the form of meteorites whose content appears, from the few tests made, to be relatively meager,[1] such accessions are not yet demonstrated.

The cycle of distribution on the earth's surface is simple. From the igneous rocks the radioactive substances are dissolved and disseminated through the waters and carried wherever they go; while from both the rocks and the waters the emanations are given forth into the atmosphere. From the air and the waters in turn the radioactive derivatives are reconcentrated into the earth, except as their disintegration becomes complete and they pass permanently, in the form of helium, into the atmosphere or are lost from the atmosphere into the cosmic regions outside.

[1] Strutt, *Proc. Roy. Soc.*, LXXVII A, 480.

The special distribution of the radioactive substances among the different kinds of igneous rocks is no doubt full of meaning, but as yet the determinations have not been sufficient to justify more than a few broad generalizations, and these must be held subject to revision.[1] It may be said safely that the igneous rocks carry a higher ratio of radioactive substance than the average sediments. The reason for this is simple. The sediments are derived from the igneous rocks, and in the process of derivation some of the radioactive matter inevitably goes into the waters and into the atmosphere, and this diversion leaves the content in derivative rocks lower than that of the original rocks. If all the radioactive matter that is lost into the waters and the air were gathered into the derivative rocks, their content should equal that of the igneous rocks from which they came, if no account be taken of the loss by dissolution.

The earlier determinations of the amounts of radium in the igneous rocks by Strutt seemed to show that the acidic class hold more radioactive matter, on the average, than the basic class, and a portion of the later determinations seem to support this generalization, but the determinations of Eve and Joly, which have been important, seem to bring the richness of the basic class into somewhat near equality with that of the acidic, and even to make the preponderance of the one class over the other doubtful. The point of special interest here lies in the inference that, if the liquefaction and eruption of the igneous rocks is dependent on the heat derived from radioactivity, the distribution of radioactive substances in the erupted rocks should be inversely proportional to

[1] The larger number of determinations of radioactivity in rock have been made by Strutt: *Proc. Roy. Soc.*, LXXVI A (1905), 88 and 312; LXXXVII A (1906), 472; LXXVIII (1906–7), 150; LXXX A (1907–8), 572; Eve: *Phil. Mag.*, September, 1906, p. 189; February, 1907, p. 248; August, 1907, p. 231; October, 1908, p. 622; *Am. Jour. Sci.*, XXII, (December, 1906), 477; *Bull. Roy. Soc. Con.*, June, 1907, pp. 3 and 9; July, 1907, p. 196; Joly: *Nature*, January 24, 1907, p. 294; *Phil. Mag.*, March 1908, p. 385; *Radioactivity and Geology* (1909), general treatment with references; Elster and Geitel: *Phys. Zeit.*, II (1900–1901), 590; III (1901), 76.

For the physics of radioactivity see J. J. Thomson: *The Conduction of Electricity through Gases;* E. Rutherford: *Radioactivity;* (1904); *Radioactive Transformations* (1906); *F. Soddy: Radioactivity* (1904); *The Interpretation of Radium* (1909); R. J. Strutt: *The Becquerel Rays and the Properties of Radium* (1904); and the papers of Boltwood, McCoy, and many others.

their temperatures of mutual solution or of fusion. But it must be observed that even if such a casual distribution prevailed in the rock-matter when first it took the liquid form, this distribution might not persist indefinitely, for selective segregation has apparently taken place during the later processes. It is quite clear that the radioactivity is concentrated in some constituents rather than others, as for example in zircon, pyromorphite, apatite, and some other minerals, and in pegmatite and some other rocks. The pegmatitic material, in segregating from a granitic magma, seems to have gathered into itself an unusual proportion of the radioactive substance of the parent mass. In the details of final distribution, therefore, the different parts of the segregated rock-material may rationally be expected to differ from one another and from the parent magma in radioactive content. The determinations thus far made, though not adequate to demonstrate this, seem to be in consonance with it. Much interest will therefore gather about the forthcoming determinations as they multiply and contribute their quota of evidence bearing on the radioactive qualities of the various species of igneous rocks.

Among the derivative and sedimentary processes it seems clear that there are modes of concentration also which have given to different sediments different contents of radioactive substances. It appears from the determinations already made that the radioactive substances are leached out of the parent igneous rocks faster than the average minerals of those rocks, for weathered igneous rocks are found to carry less radioactive matter than fresh rocks. This is in accord with the aptitude for chemical change already noted; and yet soils which are almost the type of ultra-weathered material still retain notable radioactivity, but a part of this is probably a redeposit from the atmosphere. In general, it appears that the clayey element carries more radioactive material than the quartzose sands or the calcareous derivatives.

In the deep-sea deposits radioactive matter is higher than in the deposits of the shallow parts of the ocean. In the red clays and radiolarian oozes of the abysmal depths the content is markedly greater than in the land-girting muds and sands, or the calcareous oozes of mid-depths. This is assigned in part to the removal by

solution of the lime from the original matter of the abysmal deposits, leaving them residual concentrates, and in part to the collection in the depths, in relatively high proportions, of phosphate-bearing relics (teeth, bones, etc.) with which radioactive substances are associated. It is a suggestive fact that the phosphatic nodules of the great deeps are highly radioactive compared with ordinary sedimentary material. A part of this is clearly due to the concentration of the radioactive substances after the phosphates were deposited, for fresh phosphatic material is notably less radioactive than fossilized phosphates.[1]

It appears then that the radioactive substances on the surface of the earth are subject to special agencies that lead in part to greater concentration and in part to wider distribution, and that these act co-ordinately with the general dispersing agencies that give radioactivity to the derivative rocks, to the waters, and to the air.

If it were permissible to reason from what is known of surface phenomena, particularly from the broad fact that radioactivity increases as we go from air to water, from water to sediment, and from sediment to igneous rock, it might be inferred very plausibly that radioactivity would be found to reach its maximum concentration in the heart of the earth, and certainly that the deeper parts would be as rich as the superficial ones. This presumption might very justly be felt to be strengthened by the fact that the atoms of uranium, radium, and thorium are among the heaviest known and that if the earth were ever gaseous or liquid, these heavy atoms might naturally be expected to be concentrated toward its center unless the viscosity of the fluid mass were too great to permit this, in which case the distribution should be either equable or indifferent to depth.

But Strutt[2] early called attention to the fact that if such an increasing abundance exists toward the center of the earth, or if there were an equable distribution in depth, the heat gradient as the earth is penetrated would be higher than observation shows it to be. By computations on the data then available he

[1] Strutt, *Proc. Roy. Soc.*, LXXX A, 582.

[2] *Proc. Roy. Soc.*, LXXVII A (1906), 472; LXXVIII A, 150.

concluded that a distribution of radioactive substance equal to that of the surface rocks for a depth of only 45 miles would give the rise of heat actually observed in wells, mines and other deep excavations. Later data and closer scrutiny seem to confirm the general soundness of Strutt's inference, and to make the limitations even more narrow. Joly, approaching the problem from the geological as well as the physical point of view, and with the advantage of later data, reached the conclusion that radioactivity of the amount observed at the surface, if continued to a depth ranging from 27 to 37 kilometers (17.2 to 23.5 miles), would give rise to heat equal to that implied by the loss at the surface.[1] According to Joly, however, a complete concentration of radioactivity in a shell of this depth does not meet the apparent requirements of igneous phenomena if this be assigned to radioactivity. A deeper distribution of a part of the radioactive matter and a less concentration in the outer part of the crust is felt by Joly to be required and he was led to this final statement: "If we said that the richer part of the crust must be between 9 and 15 kilometers deep, we cannot be far from the truth. This appears to be the best we can do on our present knowledge."[2] It is to be noted that these deductions are reached on the supposition that all the internal heat given out arises from radioactivity; no margin is left for any original heat or for secular heat from any other source. On the other hand, the computations seem to take no account of loss of heat by means of igneous extrusions.

These remarkable deductions raise two questions of radical import:

(1) If supplies of heat are generated currently by radioactivity in such abundance that it is necessary to put these severe limits on the distribution of radioactive substances, must we abandon entirely all further consideration of supposed supplies handed down from a white-hot earth or from any other form of the primitive earth?

(2) Is there among the internal processes previously postulated any that provides a way in which such a concentration at

[1] *Radioactivity and Geology* (1909), 175.

[2] *Ibid.*, 183.

the surface might naturally have taken place, or must we find a new geological process to fit the new thermal difficulty?

The rigor of the dilemma is softened somewhat by noting that the deductions of Strutt, Joly, and their colleagues are based simply on comparisons between the heat-generating power of radioactive substances in the crust and the conductive power of the crust. The functions of igneous extrusion as a mode of transfer of internal heat do not seem to be taken into account. This is not unnatural since the heat carried out by extrusive matter and by waters heated by igneous intrusions has not usually been regarded as an important factor in reducing the high temperature inherited by the earth under the older view. But the movement of igneous matter and of waters and gases heated by it has been made to play an essential part in the working concepts that have been based on the planetesimal hypothesis. There will be occasion to return to this critical difference of view.

When the apparent excess of thermal riches arising from the new source was first realized an escape from the dilemma raised by it was sought in the natural supposition that the disintegration of uranium and thorium was restrained by pressure in the depths of the earth, and that, though present there, their activity was greatly subdued or possibly inhibited altogether. This plausible explanation was diligently tested; but the general tenor of experiments on the effects of pressure, notably those of Eve and Adams[1] in which the pressures were carried to intensities sufficient to cover earth-pressures to the depths supposed to limit radioactivity and beyond, showed no appreciable restraint on the disintegrating process. It seems necessary, therefore, in the present state of evidence, to accept the inference that the radioactive substances are really concentrated toward the surface, and that the radioactive content in the depths of the earth is of a much lower order.

It does not fall to me to adjust the new requirements to the older view of the earth's internal temperatures based on a molten earth, for other considerations led me to the abandonment of this view before the advent of the new issue. I must leave it to those who hold to the molten hypothesis to battle with its new perils.

[1]*Nature*, July, 1907, p. 269.

With such a plethora of heat at the start as a molten earth implies and with a new agency whose current production of heat would seem to be excessively great if its prevalence were not constructively minimized, it is not with regret that I feel absolved from the task of finding a reconciliation between this venerable view and the requirements of juvenile discoveries.

The discussion of Professor Joly,[1] though not explicitly based on the theory of a molten earth, is sympathetic with the general tenets associated with such an earth, and his treatment may be taken as offering the best approach to a reconciliation that seems now possible.

It is interesting to note, however, that when Professor Joly reached the critical question of a possible mode by which the surface concentration of radioactivity could have come about (*Radioactivity and Geology*, 184) he turned to the accretion or planetesimal hypothesis. While he indicated the central line of action on which the concentration might have been accomplished he left without elucidation the line of reconciliation between the heat gradient postulated by the planetesimal view and the gradient he deduces from radioactivity.

It is the chief purpose of this paper to set forth what seems to me to be the true harmony between the new light shed by radioactivity and the tenets of the planetesimal view as shaped by me before the discovery of radioactivity and to show the co-ordination of the planetesimal and radioactive agencies in jointly leading to the results observed. To this end it is necessary to sketch with some care the thermal features of the planetesimal view in the form to which preference was given from the start so that it may be clear just what part radioactivity plays in the assigned co-operation.

On the assumption that the earth grew up by the accession of planetesimals, whatsoever heat arose from the condensation of the nucleus about which the growth took place centered in the innermost parts and can affect present surface phenomena only by transfer. The infalling matter that is supposed to have built up the earth to its mature size must have generated much heat by

[1] *Radioactivity and Geology*, 154–82.

its impacts, but as the infall is held to have been slow and as this heat was superficial, it may be assumed that it was largely radiated away before it became so deeply buried as to be permanently retained, and so the most of the heat of impact may be regarded as negligible.[1] In the original shaping of the planetesimal hypothesis (before the discovery of radioactivity) the main source of internal heat was made to spring from the compression which the deeper parts of the earth underwent by the increase of its mass as the planet grew to maturity. This chief source was supposed to be abetted by heat springing from the rearrangment and recombination of molecules within the mass as time went on. Changes in the distribution of the heat after it was developed were supposed to follow by means of conduction and especially by the transfer of hot fluid matter carrying latent heat.

It is important to the present discussion to note that the heat generated by pressure did not affect the outer part and that it began to be sensible only when those depths were reached at which the rocks suffered appreciable compression from the weight of the rock-mass above them. Thus the heat gradient so generated would rise only slowly in the outer part of the earth and faster in a systematic way toward the center for a considerable depth, if the compressibility of the rocks remained uniform to indefinite depths. If the compressibility fell off as compactness increased the rate of thermal rise toward the center would have been slower. Compressibility at the surface seems to be nearly proportional to pressure, but the compressibility of rocks after they have been compacted by such pressures as are attained at considerable depths is unknown, and it is necessary to proceed here by alternative hypotheses. The extrapolation of the curve found under experimental pressures is of course entitled to precedence and this alternative was used as the basis of the first approximation to the heat curve of the earth's interior. For the other factors, such as specific heat, necessarily taken into account in the computation, assumptions as near to known facts as possible were made. On these assumptions it was found that the heat generated between the surface and the center of the earth may be represented by a curve

[1] Chamberlin and Salisbury, *Geology*, I, 533.

which rises at a very low rate near the surface and is followed by a slowly *increasing* rate for about one-third the distance to the center, beyond which it rises at a *decreasing* rate to the center; or, if traced from the center outward, this computed curve of temperature declines faster and faster at every step for about two-thirds of the distance and then declines less and less rapidly to a vanishing-point near the surface. Hence if conductivity be assumed to be the same at all depths, the outward flow of heat on such a gradient would increase in rate from the center to the two-thirds point and then grow slower toward the surface, from which it follows that, on these assumptions of uniform compressibility and uniform conductivity taken by themselves, the internal heat should have been progressively lowered in the deep interior and raised in the more superficial parts. The conductivity of rocks is so very slow, however, that its effects at the surface under the conditions named cannot have been large up to the present unless the earth is much older than even radioactivity seems to imply.

This first approximation to a theoretical curve of heat, even when modified by conduction, has not been supposed to represent the actual distribution of heat at the present time, for reasons that follow.

There is ground to think that compressibility falls off as increased degrees of compactness are attained. In working out the curve which was published in *Geology*, I, 566 (Chamberlin and Salisbury), Dr. Lunn used as a guide the Laplacian law of density which postulates that density varies as the square root of the pressure. This distribution of density harmonizes fairly well with such astronomical tests as are available and gives a mean density for the earth which is near that required by the earth's total weight. The assumption that the increased density of the interior is all due to compression, however, makes no allowance for the probable transfer of lighter matter to or toward the surface by extrusive action which would tend to increase the mean specific gravity of the residue. The curve of Dr. Lunn may be regarded as a second approximation.[1] But this, as noted, does

[1] *Year Book No. 3*, Carnegie Institution of Washington, 1904, p. 156; also "Geophysical Theory under the Planetesimal Hypothesis," Section II of "Tidal and Other

not take into consideratiion the effects of liquefaction and extrusion and these in the planetesimal view are of the first order of importance. The theoretical curve mathematically deduced by Dr. Lunn is, however, an indispensable basis for a third approximation in which the effects of liquefaction and extrusion are taken into account.

Before passing on to consider liquefaction and extrusion, it is well to note that the Lunn curve based on the Laplacian law of density also is low near the surface and that its rate of rise is much below that of the temperature gradient observed in wells and mines. Dr. Lunn, on assumptions carefully specified in his discussion in the paper cited, found the rise in the first 200 miles only 330° C.

This low development of heat in the outer part of the earth seemed at first thought to present a difficulty of a rather serious nature, but it was believed to be met by the effects of liquefaction and extrusion, and these were made the chief basis of an additional approximation to the actual temperature curve (Chamberlin and Salisbury, *Geology*, I, 265–67). It was held that the rising heat of the interior would reach the temperatures of fusion or of mutual solution of some ingredients in the mixed material much earlier than that of other ingredients, and that the ascent of the portion that became molten carrying its latent as well as sensible heat into the cooler outer zone would necessarily raise the temperature of that zone. It was held that the continuation of this process served as a constant influence tending to retard the rise of temperature in the deeper zone where the partial liquefaction was in progress while it progressively raised that of the outer zone into which the liquid rock was intruded, whether it lodged in the crust or passed through it to the surface. This extrusive process was supposed to have continued to the present day and to have resulted in a permanent adjustable working curve of accommodation between thermal, fluidal, and mechanical conditions. This curve, except in the cool crust, was essentially identical with the fusion-

Problems," *Publication No. 107*, Carnegie Institution of Washington, 1909, pp. 169–231; for a summary and figure of curve see also Chamberlin and Salisbury, *Geology* (1904), I, 566.

solution curve, whatever that might happen to have been for the time being under the local conditions of pressure, state of strain, nature of material, means of escape, and other properties that affected liquefaction and extrusion. It was regarded as essentially *a curve of equilibrium between solidity and liquefaction* accommodated to the conditions present at each depth and at each stage and was *maintained automatically. The actual curve as thus assigned continued always to be essentially the liquefaction curve after that was once attained.*[1] The view excludes automatically all internal temperatures higher than the local liquefaction temperatures and of course excludes all pervasive gaseous conditions except that of the interspersed and occluded gases of the mixed mass. These interspersed gases assisted extrusion and hence were among the parts most freely extruded. All theoretical inferences based on temperatures higher than the temperatures of liquefaction are excluded from consideration under this view by its very terms.

Certain structural conditions postulated by the planetesimal hypothesis greatly favored this automatic action. The infalling matter was assumed to have built itself up in a very heterogeneous manner with the result that the mass of the earth was an intimate mixture of all the kinds of material that made up the spiral nebula from which it was supposed to have been gathered. As this mixed matter was heated by compression, some parts of it must certainly have reached temperatures at which they could go into mutual solution or into fusion while as yet other closely associated parts had not reached temperatures that permitted such action, and as the rise of temperature was very slow by the terms of the hypothesis the passage of successive parts into liquefaction was widely separated in time. Fluid parts thus came temporarily to be intimately mixed with solid parts. These fluid parts, in the act of passing into solution or fusion, absorbed the necessary energy of liquefaction at the expense of the increasing supply. On their ascent into the crust they heated it. If they lodged there and resolidified they gave up their heat of liquefaction. If they reached the surface the residue of heat, both sensible and latent, was lost. By such liquefaction and transfer these portions served

[1] *Op. cit.*, 567.

to protect the residue in the deeper parts from liquefaction for the time being and the continuation of the process extended the protection to such residue as continued to persist.

It is not necessary to offer evidence that ascent of liquid rock took place in great quantities in the early geologic ages and has been more or less active in all ages down to the present. One of the extraordinary facts of the Archaean terranes is the extensive lodgment of liquid rock in the crust, and even in later ages batholitic phenomena have attained surprising magnitudes. The extrusion of molten rock at the surface was a very pronounced phenomenon as late as the Tertiary and is still an active process. As this extrusive action was widely distributed over the surface at various altitudes and at various stages through great lapses of time and yet was never really very massive when measured in terms of earth-volumes at any one time or place, it is of critical value here to note that the view built on the planetesimal hypothesis appeals to a special set of conditions of liquefaction and extrusion which are peculiarly favorable for selective work in small masses and unfavorable for *general* liquefaction. In this respect the conditions it assigns stand somewhat in contrast with the conditions usually assumed to be the natural inheritances from a general molten condition. The inference that *general* liquefaction would take place on any general rise of heat is natural enough in a case in which the whole mass has been solidified from a previous molten state, for such a mass might be presumed to return massively into its former state on a reversal of conditions; but the heterogeneous condition of the mixed matter of the interior postulated by the planetesimal view is not favorable to a simultaneous fusion of the whole mass or any large continuous part of it unless extrusion be restrained until a high temperature is attained. Such restraint is here held to be dynamically inconsistent with the mechanism and the stress conditions of the earth-body. In addition, therefore, to such a mixed state of material in the interior as peculiarly to invite selective liquefaction as the temperature slowly rose, the planetesimal view postulates a set of stress agencies that worked co-operatively to effect extrusion as fast as liquid matter accumulated in workable volume.

In considering stress effects, it is necessary scrupulously to distinguish between *hydrostatic* stresses which operate equally on all sides of a given unit and so only produce compressive and like effects, and *differential* stresses which promote movement and change of form. The effect of differential stresses on the solid parts of the earth is primarily to produce strains; the effect on liquid parts is primarily to produce flow and relocalization. And so by reason of this difference of effect, a general differential stress on any large part of the earth is apt to become locally sub-differentiated when solid and liquid parts are intermixed, especially if the liquid and solid states of these parts are partially interchangeable because their temperatures lie so close to the line of equilibrium between solidity and liquidity. Tensional strains promote liquefaction in bodies constituted as most rocks are; compressive strains resist liquefaction in such bodies. And so general differential strains co-operate with temperature in promoting or in restraining the passage of matter from the one state to the other according to the nature of the strain and thus have some influence in directing and facilitating movement as well as in forcing it.

Some of the differential stresses in the earth are essentially fixed and constant, such as the direct pressures that arise from the action of gravity. These stresses range from one atmosphere at the surface to about three million atmospheres at the center. Such pressures tend to force lighter bodies toward the surface while heavier bodies seek the center in ways so familiar that we need not dwell on them, nor on the fact that, since molten rock is usually lighter than the same rock in a solid state, this static differential stress of gravity presents a general condition that favors the ascent of liquid rock. So also the incorporation or generation of gases in liquid rocks tends to lessen the specific gravity and increase the mobility and hence the gaseous element adds another general influence that favors ascent.

In addition to these very general and persistent stresses, more special differential stresses have arisen at various times from inequalities of accession, from transfers of matter, from loss of heat, and from other varying agencies, and these have been present,

in one form or another, at nearly all times in the earth's history. They have often been cumulative until they reached diastrophic intensity and manifested themselves in impressive deformations. That these have been effective agencies in forcing the movement of liquid parts within the earth in the lines of least resistance and of best accommodation to existent conditions is scarcely debatable.

In addition to the simple stresses of gravity and to the diastrophic stresses, there have been superposed at all times a series of stresses of a rhythmical pulsatory nature acting throughout the body of the earth. The nature and function of these has not been so generally recognized. These stresses are derived from the differential action of the gravity of neighboring bodies, particularly that of the moon and of the sun. Tidal and tidelike stresses and strains have swept through the earth's body in a constant cycle bringing to bear on each part a perpetual succession of compressive and tensional stresses and strains alternating with one another. The effect may be pictured as that of a minute kneading of the earth-body. There is not only a superposition of pulsating strains on the more static strains but a superposition of pulsating strains on pulsating strains. The pulses of the twelve-hour body tides are overrun by tides of longer periods and these are attended by shifts of direction of strain, all of which tend to knead the mixed matter to and fro and promote insinuation of the liquid parts along the lines of escape.

Underlying all these rhythmical strains there has been ever present a variation in intensity from center to surface. Sir George Darwin has shown that the tidal stresses generated by the moon at the earth's center are eight times as great as those at its surface. Each compressive strain squeezes the lower part of each liquid vesicle or thread more than the upper part.

The coexistence of these pulsatory and periodic strains with the simple static stresses of gravity and the less constant diastrophic stresses sufficiently implies their co-operative nature. All these three classes are either differential stresses or have factors or phases that are differential, and so, in specific local application, they are all transformed into sub-differentiational effects on the liquid and solid parts.

Under the planetesimal view the joint effect of these differential stresses and their resulting strains has been at all times to force toward the surface liquefied rock as fast as it gained workable volume. Much aid in insinuating itself along liquid lines and in fluxing a more open path until the fracture zone was reached, is assigned to the mixed nature of the material and to the local strains imposed by the stress agencies. The whole picture centers on the fundamental dynamic proposition that *energy in mobile and expansive embodiments seeks the surface, while its fixed embodiments are forced more firmly together toward the center.*

The extrusion is held to have begun as soon as the susceptible matter took the mobile form. Possible exception is admitted in the case of matter that may have been too dense to be forced to the surface. However, a high density of small masses enmeshed in masses of less density could only contribute to an average effect so long as a high state of viscosity was retained, and a relatively high viscosity for the small mobile masses, naturally arose from the close balance between the liquid and solid states. Such a condition seems equally to be implied by the remarkable mixtures of dense and light matter often seen in the igneous rocks.[1]

The matter forced early to the surface is held to have been buried by further accretions to the growing planet, later to have been subject to a second liquefaction and extrusion, a second burial, and so on. Progressive selection and reselection are postulated until the growth essentially ceased. Since then a more complete selection and concentration of the eutectic material at the surface has been in progress as far as further generation of internal heat has furnished the actuating agency.

Now if this picture in its working details and in its rather sharp antithesis to the older view is clearly in mind, the part which the radioactive substances may be supposed to play in co-operation with this mechanism without changing the general conception is little less than self-evident. The radioactive particles are sources of self-generated heat. Under the planetesimal view the radioactive substances were promiscuously scattered through the mixed mass as it was gathered in heterogeneously from the nebula

[1] Chamberlin and Salisbury, *Geology*, II, 121–22.

by the crossing of the planetesimal orbits. No original segregation of this class of matter more than of any other heavy material is assignable. The relative amount of the radioactive matter, at least of the classes now known to be radioactive, must have been extremely small and its influence on the specific gravity of the matter with which it was mixed must have been negligible. The self-heating effects of these disseminated particles were necessarily expended first upon themselves and next upon adjacent matter, and, other things being equal, this homemade heat should have given these parts precedence in passing into the mobile state. Normally the mixed units that inclosed a radioactive particle should have been as susceptible of partially passing into the liquid state as similar units that were free from radioactive matter. The special source of heat should have turned the balance in favor of the unit immediately surrounding the radioactive particle. Thus the radioactive matter normally became involved in the mobile matter and passed with it to or toward the surface.

With every stage in the growth of the earth and with every reburial of the radioactive material a second similar preferential action should have followed. On the essential completion of the growth of the earth a more complete concentration of the self-heating matter should have followed, for additional weighting by accretion had essentially ceased and compression had become essentially static while the self-heating competency of the radioactive matter, though no doubt somewhat reduced by consumption, was probably more efficient *relatively* in the production of heat than it had been during the more active stages of growth.

It seems clear, therefore, that at all times after the volcanic process was well under way radioactivity should have been relatively most active in the outer part of the earth and should have become especially so in the latest stages of the earth. It is therefore not too much, perhaps, to claim that a specific basis in favorable conditions and a definite working mechanism for an effective concentration of self-liquefying matter at the surface was postulated in a singularly apt way before radioactivity was discovered, and quite irrespective of the dilemma which its discovery has involved.

Reciprocally radioactivity greatly eases the burden laid on compression in the outer part of the earth where it is least competent and where resort was had to igneous intrusions from below to give the crust its observed temperatures. With the addition of the new thermal agency the extrusions are presumed to play much the same part as before but more actively, as they must now be supposed to meet the liquefying effects both of compression and of radioactivity. If there was ground before to question the efficiency of compressional heat, aided by such other sources as were formerly assignable, to give rise to the high degree of igneous activity that marked the Archaean ages and to sustain the lesser igneous action of later periods down to the present, this doubt is amply resolved by the combined efficiency of compression and radioactivity. In any case it is certain that a large amount of energy has been brought to the surface and radiated into space.

Radioactivity also comes to the aid of other agencies of extrusion in the peculiar service it renders in opening a path for the outward movement of the liquid matter. In the liquefying process, as we have seen, the radioactive particles should have been gathered by their self-heating action into the liquid vesicles and have been forced outward with them. The self-heating property thus became an endowment of the liquid and gave to it thermal efficiency in dissolving and fluxing its way. This efficiency was continually renewed by the progressive disintegration of the radioactive atoms. It is not improbable that the liquid threads were thus aided in a very special way in boring upward, for it seems obvious that the part of the liquid which carried most of the self-heating constituent would come to have the highest temperature, the lowest specific gravity, and the largest gaseous factor—for the disintegration produced gas emanation and helium in addition to the gases generated by the heat alone—and hence would take the uppermost position and bring its liquefying influences to bear on the solid matter which lay between it and the surface toward which it was pressed. The very mechanism may thus have kept the most effective part at the point most critical to its ascent.

While this outline falls far short of an adequate discussion of the relations of radioactivity to the planetesimal hypothesis, it

will perhaps suffice to point out the line of co-operation of the new thermal agency with the new genetic hypothesis. The two seem to co-operate happily. Jointly they seem to furnish a promising basis for a revised thermal geology in harmony with accumulating geologic data in various lines and with the growing evidence of the elastic rigidity of the earth-body as a whole. At least the concentration of the radioactive substances at the surface seems to be aptly explained, and the mechanism that conserves the solidity of the earth falls into consonance with the new experimental evidence of an elastico-rigid body-tide which seems scarcely less than decisive.

There is perhaps one further point, among the many remaining, that should be briefly touched here lest there seem to be an outstanding incongruity in the present distribution of vulcanism. If there is a progressive supply of heat in the earth's crust springing from radioactivity and if it is this that actuates vulcanism, why are not volcanoes more uniformly distributed over the face of the globe? A general sub-uniform distribution is a natural deduction from the postulates. The distribution of pits on the moon, assuming that they are volcanic craters, fairly fits the picture that normally arises from the action of such an agency. Especially is this true if vulcanism is effected in so selective and so individual a way as we have indicated. Why has not such a distribution persisted on the earth? It will perhaps be conceded that the prevalence of vulcanism in Archaean times fairly satisfies the terms of the case. But at present volcanoes are rare in the primitive shields that form the nuclei of the continents while volcanoes are concentrated about the borders of the continents and in the deep basins and are particularly abundant where the great segments of the crust join one another. The primitive shields are indeed intimately scarred and shotted with igneous intrusions of the early ages, but they are almost immune now.

There seem to be two lines of plausible explanation. These old embossments have suffered denudation from an early date and the matter removed has been carried to the borders of the adjacent basins. According to the hypothesis of concentration at the surface, this lost matter carried a relatively high proportion

of radioactive substance. When this was in the state of a mechanical sediment it was chiefly deposited on the borders of the basins; when it was in solution it mixed with the waters of the oceans and was later largely concentrated in the oceanic precipitates. Thus the prolonged process of denudation cut away the radioactively richer part of the shield and added it to the undenuded crust of the continental borders and the oceanic basins, thinning the one and thickening the other in a special radioactive sense. Besides this the lower crust in the denuded area was lifted relatively toward the cold surface, while in the depositional area it was relatively depressed beneath a growing radioactive mantle.

The rise of the denuded embossments of the crust was attended by elastic expansion of the whole sector of the earth beneath, since the gravitative pressure was lessened throughout. A lowering of the melting-points indeed attended this and doubtless a change also of the mutual-solution conditions, but this was anticipated by the elastic expansion and its instantaneous cooling effects, a point usually overlooked.

In addition to this immediate expansional effect, it is held by some geologists, with whom I am glad to associate myself, that the protruding portions of the continents tend to lateral creep and that this carries with it tensional effects as well as some further elastic expansion. At the same time, the penetration of surface-water is promoted and this aids effectively in carrying off the heat of the outer crust. It may be observed that while meteoric circulation penetrates to considerable depths beneath land surfaces there is little reason to think that there is any effective circulation to appreciable depths in the ocean beds.

One further agency is believed to co-operate with these at a lower horizon but this can be touched only with reserve as it involves joint studies yet in progress upon which I do not feel at liberty to draw further than may be necessary merely to indicate their bearing on this particular problem.[1] In a previous part of

[1] The studies are common to my son, Rollin T. Chamberlin, and myself and in the particular here applicable the junior partner is the leader in pursuance of lines of inquiry growing out of his studies on "The Appalachian Folds of Central Pennsylvania," *Journal of Geology*, XVIII, No. 3 (April-May, 1910).

this paper the selective influence of strains on fusion and solution was cited. There seems little doubt that a similar influence is exerted by the great zones of strain that are developed in the earth by diastrophic agencies. Among the tentative distributions of these under study, a specific system seems more probable than others and this is of such a nature as to direct fluid matter, particularly any that may arise at considerable depths, toward the lines that are affected by volcanic extrusions.

THE WING-FINGER OF PTERODACTYLS, WITH RESTORATION OF NYCTOSAURUS

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The question whether the wing-finger of pterodactyls is the fourth or the fifth has been disputed for the past eighty years, though for the past forty years authors have been almost unanimously agreed that it is the fifth. The first writer of credibility who expressed an opinion on the subject was Cuvier, who considered it the fourth. His reasons for so doing, as published in his Ossemens Fossiles, are today, I believe, unanswerable, and to him should be given the credit, and not to H. v. Meyer, for the correct recognition of the finger. I quote his remarks in full:

> En fin il a ce doigt énormément prolongé en tige grêle, qui caractérise éminement notre animal.
>
> Il a quatre articulations sans ongle. Le quatrième doigt des lézards aurait cinq articles et un ongle; mais, dans les crocodiles, il n'a que quatre articles, et il est dépourvu d'ongle comme ici; seulement il n'y éprouve pas ce prolongement extraordinaire.
>
> Le crocodile et les lézards ont en outre un cinquième doigt qui dans les, lézards a quatre articles, et dans le crocodile est réduit à trois sans ongle.
>
> Il paraît que dans l'animal fossile il ne reste qu'un vestige de cinquième doigt, mais assez obscur et sujet à contestation.
>
> Le grand doigt est probablement le quatrième, car c'est aussi le quatrième qui est le plus long dans les lézards.
>
> Les trois autres le précédaient dans l'ordre inverse du nombre de leurs articles.

The first author to adopt the other view, that the finger is in reality the fifth, was Goldfuss, who, as Plieninger has shown in his full and reliable review of the subject, thought he saw in the pteroid bone a first finger, accidentally misplaced in his specimen, and in which he thought he recognized an additional phalange even. H. v. Meyer early adopted Goldfuss' view, as shown in the following quotation: "Es zeichnen sich diese Thiere vor allen anderen wirklich dadurch aus, dass der Finger sie zum Fliegen befähigte,

und zwar nur ein Finger, die Ohrfinger, welche wegen der Kleinheit womit er in der Hand anderen Geschöpfe sich darstellt auch der kleine Finger genannt wird" (*Paleontographica* [1851], 19).

But Meyer soon returned to the Cuvierian position, calling the first of the small, clawed fingers the thumb. I can find no independent arguments of Meyer giving the reasons for his views; indeed in various places he is more or less obscure, referring to the "Flugfinger" as the "Ohrfinger," though there can be no doubt but that as early as 1860 he had, as I think, correctly recognized the digit as the fourth. Owen in his *Paleontology* and *Comparative Anatomy of Vertebrates* figures four small, clawed fingers in front of the wing-finger, which he calls the fifth. Later he reverted to the Cuvierian view. Goldfuss's views were followed by Oscar Fraas and most modern authors, including Marsh, Zittel, Plieninger, and Eaton. In 1904,[1] without at the time having read Cuvier's remarks on the subject, I published a brief article in the London *Geological Magazine* giving reasons for the older view, that the finger is in reality the fourth, as based chiefly upon the recognized normal number of phalanges in the hands of reptiles.

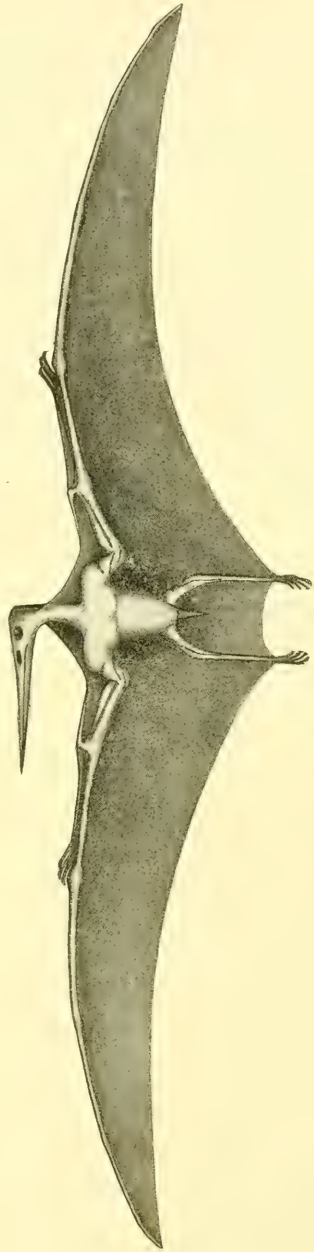

FIG. 1.—Restoration of *Nyctosaurus gracilis* Marsh, by Herrick E. Wilson

[1] "The Fingers of Pterodactyls," *The Geological Magazine*, 1904, p. 59.

Two years later Plieninger[1] discussed the subject fully and well, reaching no positive conclusion, though evidently favoring the Goldfuss view that the finger is the fifth. He showed that Goldfuss, and not Fraas, as I had thought, was the first author to suggest the identification of the pteroid with the first finger, and corrected Seeley's statement that Meyer had so recognized it. We have seen from the quotation that Seeley was really not so far wrong after all, since Meyer did at one time consider the "Flugfinger" as the "Ohrfinger." Finally Abel[2] in a recent paper has restated the problem, adopting the original Cuvierian view.

As bearing upon this question we have been fortunate in recent years in determining the intimate structure of the hands and feet of several of the early reptiles, from which I may say with entire assurance that, until the close of Carboniferous times, and probably till the close of Permian times, the phalangeal formula for reptiles was the primitive one of 2, 3, 4, 5, 3 for the front feet; 2, 3, 4, 5, 4 for the hind. Plieninger has raised a question in the cited paper whether the formula 2, 3, 4, 4, 3, as seen in the crocodiles, was not really the primitive one for the hands instead of 2, 3, 4, 5, 3, as found in the generality of modern lizards and in *Sphenodon*. In the accompanying figures the front limbs of three of these reptiles, from the so-called Permian of Texas and New Mexico, are shown, made out with certainty in nearly every detail. In Fig. 4 the distal three phalanges of the fourth finger have not yet been positively fixed, but inasmuch as the fourth digit of the hind foot of the skeleton to which the figured hand pertains has definitely five phalanges, there can be no doubt of the number in the same digit of the hand. In Figs. 2 and 4 the bones of the forearm and wrist are shown in a horizontal plane without the foreshortening of the oblique position that they really had in life, and which is shown in Fig. 3. Fig. 2 is that of a cotylosaur, probably belonging in the suborder Pareiasauria, while Figs. 3 and 4, *Ophiacodon*[3] and *Vara-*

[1] "Ueber die Hand der Pterosaurier," *Centralbl. für Mineralogie, Geol., etc.*, 1906, p 399; also *Paleontographica*, LIII (1907), 301.

[2] "Die Vorfahren der Vögel," *Verhandl. der K.K. zoologisch-bot. Gesellsch.*, LXI (1911), 163.

[3] The full description of this genus will appear shortly in a paper by Dr. Case and the writer.

nosaurus, are zygocrotaphic reptiles that may be included in the order Theromorpha or Pelycosauria.

FIG. 2.—Right front leg of *Limnoscelis* Williston, a cotylosaur reptile from the Permian of New Mexico. A little less than one-half natural size.

In all these forms it will be observed that the fifth digit is much reduced, more so than in the hind feet of the same animals. The number of phalanges in this finger in each is three and no more; this is positive. Furthermore it will also be observed that the supporting carpale 5 is reduced or wanting in all; that is, the loss of this bone, the rule in all later reptiles, had begun even before the close of Carboniferous times.[1]

It may therefore be assumed with assurance that the ancestors of the pterosaurs had the phalangeal formula for the hand of 2, 3, 4, 5, 3, with the fifth finger much reduced in size and its supporting carpale 5 greatly reduced or entirely lost. In adaptation to aerial flight the pectoral girdle[2] and front limbs in the pterodactyls have been greatly modified throughout. In *Pteranodon* and *Nyctosaurus*, the most highly specialized, but three carpal bones remain, a proximal one, doubtless the fused radiale, intermedium, and ulnare; a lateral carpal for the support of the pteroid, which may be either the centrale or the first carpale; and a distal one, which in my opinion represents the fourth carpale alone; which, it will be seen, is the largest in reptiles. The carpale bearing the "Flugfinger" is always the larger; in *Pterodactylus* there is another, smaller one in front bearing the anterior metacarpals. I cannot believe that this carpale is the reduced or lost fifth carpale of the ancestral pterosaur carpus, nor that the wing-finger has migrated from its own vestigial carpale to the enlarged fourth while the fourth has migrated to a more anterior carpale. From the carpus then of pterodactyls it would seem highly probable that the carpale is the fourth and that it supports its proper finger the fourth, and not the fifth.

As has been known since the time of Cuvier, the phalangeal formula in pterodactyls, beginning with the first clawed finger, is

[1] I may mention here that evidence is accumulating to prove that the so-called Permian of Texas, or at least its lower part, and of New Mexico, as well as of Illinois, really pertains to the upper part of the Pennsylvanian.

[2] In my recent work on *American Permian Vertebrates*, p. 58, fourth line from bottom, occurs an unfortunate error, due to the omission of a qualifying phrase, "absent 'among nonamphibious reptiles,'" whereby I say that the supracoracoid foramen is wanting only among Pterosauria, when its absence in the Plesiosauria, most Ichthyosauria, Phytosauria, Chelonia is known to all.

2, 3, 4, 4, to which there are probably few or no exceptions. The first three of these agree absolutely with the normal and primitive formula of the first three digits. The fourth pterodactyl finger has

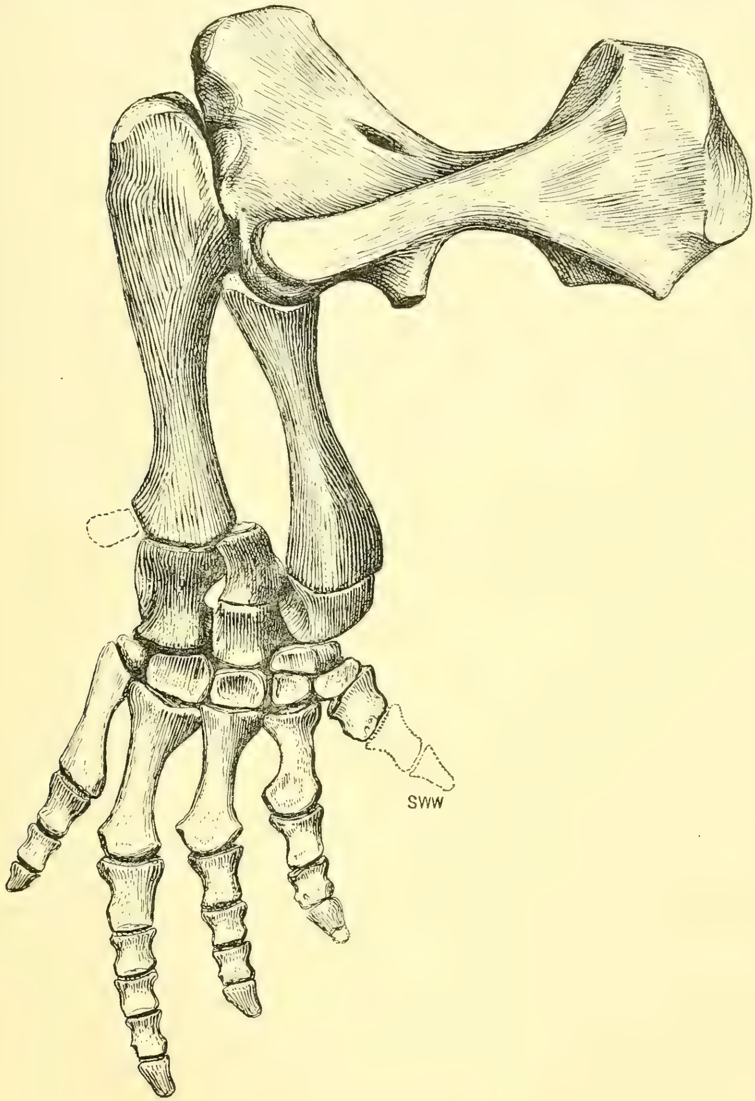

FIG. 3.—Right front leg of *Ophiacodon* Marsh, a theromorph reptile from the Permian of New Mexico. Two-thirds natural size.

but four phalanges, one less than the normal number, and quite that of the crocodiles; that is, as I have previously urged, it lacks the claw. In the acquirement of a membrane-bearing function this is precisely what would be expected in any finger, and is what occurs in the bats, as Abel has said. That the claw gradually elongated, changing its function from prehension to supporting, seems highly improbable. This finger then answers all the requirements for the fourth. If, on the other hand, in consonance with the Goldfuss theory, it is the fifth digit which acquired the membrane-supporting function, not only must the claw have changed its function and become elongated but a new phalange must have been added to the finger. Although among aquatic reptiles hyperphalangy is a common characteristic, we know of no instance among terrestrial vertebrates that I can recall where an additional phalange has been acquired, in either the front or the hind feet. And, if the Goldfuss theory be true, not only must there have been hyperphalangy in the fifth digit, but hypophalangy in the four preceding digits; that is, in the acquirement of a wing function, an increase and loss of phalanges must have occurred concurrently in the hand. I cannot believe that this was the case. Had we not to deal with the peculiar bone called the pteroid, articulating with the carpus and turned backward toward the elbow, the question of the homology of the wing-finger would doubtless never have been raised.

It is the pteroid, then, which has caused all the dispute, from the necessity of accounting for the bone, which, other than a misplaced first metacarpal, seems inexplicable. Two derivations have been imputed to it, as a sinew bone, and as a sesamoid bone. In favor of its being merely an ossified sinew is the fact that, in the remarkable specimen I have described of *Nyctosaurus,* seven well-ossified tendon bones are seen lying by the side of the forearm and hand, elongated bones with one end flattened and the other attenuated. In favor of the latter view that it is merely a sesamoid bone developed in the tendon of some carpal muscle originally is the fact that sesamoid bones do occur elsewhere in the pterodactyls. In the above-mentioned specimen of *Nyctosaurus* I found one lying over the end of the radius and another over the outer end of the coracoid; and I have seen them often in *Pteranodon.* Sesamoid bones have

bursal sacks and synovial joints. That the pteroid bone originated as a tendon or sesamoid bone is quite possible and even probable, but that the bone finally acquired another function, at least in the most highly developed forms, would seem to be very probable. The function that has generally been ascribed to it is that of a "Spannknochen" or tensor of the patagial membrane in front of the elbow. Under the assumed relations of the membrane to the front of the arm I have protested against this theory, since the fact is that there could have been little or no membrane in this region to be rendered tense, provided the membrane terminated, as is usually assumed, at the shoulder. Under the assumption that it really served as a "Spannknochen" I have suggested in an earlier paper that the membrane continued beyond the shoulder along the side of the neck to the skull.

In the accompanying restoration, Mr. Herrick E. Wilson, of the University of Chicago, after careful study, has embodied these views, based upon my skeletal restoration of *Nyctosaurus*. I believe that this restoration comes nearer to the real appearance of a pterodactyl

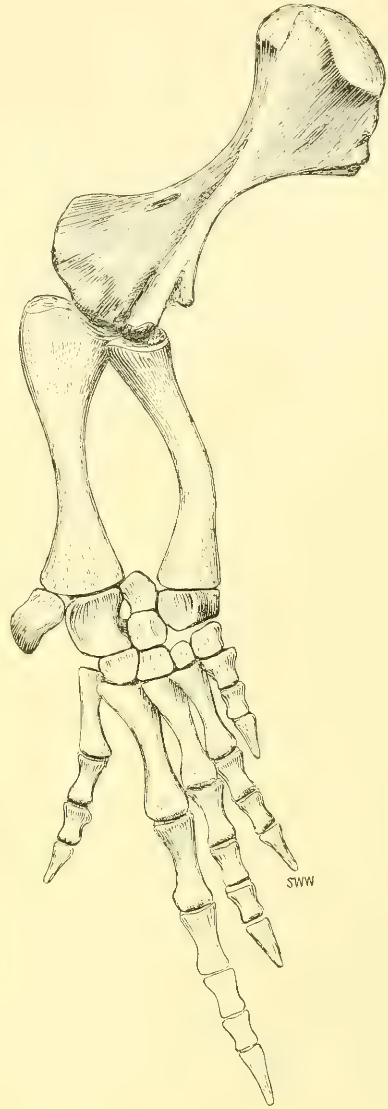

FIG. 4.—Right front leg of *Varanosaurus* Broili, a theromorph reptile from the Permian of Texas. Seven-tenths natural size.

in life than any that has hitherto been published. That the membrane extended on the neck is of course yet a hypothesis based upon the mode of development of the parachute in flying animals of today, and especially upon the structure of the pteroid bone and its relations to the forearm and shoulder. It is a fact that this bone seems to be better developed in *Nyctosaurus* than in other known pterodactyls, reaching by its pointed extremity pretty well toward the shoulder. If it was divaricated from the arm, as its perfect ball-and-socket mode of articulation with the carpus would indicate, and not inclosed in a muscle at its pointed extremity, its function as a supporter of a membrane in front of the elbow can scarcely be taken into consideration. With the membrane extending past the shoulder to the neck it would have had a distinct function as a "Spannknochen" and not otherwise.

Objection may be raised against the wide expanse of membrane between the legs. That the membrane extended to the tarsus on the peroneal side of the legs I think now hardly admits of doubt; the animals would hardly have been "flugfähig" were the legs wholly free, since the wing membrane would have been too narrow to serve as a parachute, and since the legs with their attached membrane must have functioned much like the tail feathers of modern birds in the control of flight. *Rhamphorhynchus gemmingi* has been restored by Zittel without membrane between the legs, but such a condition must seem impossible for such a flying creature. With the wings extended and the membrane connected with the ankles, there must have been a constant and considerable abducting strain on the legs, which must have required a constant muscular tension to withstand; and the legs, in the later pterodactyls at least, seem too frail for such tension. The head of mammals in the horizontal position is kept in place, not by muscular action, which would be unbearable, but by the elastic ligament of the neck. Something like this must have been necessary to withstand the constant abducting tension of the legs of pterodactyls in flight, and I assume that this was the function of a tense membrane between the legs, as well as that of directing flight. It has been suggested that the border of this membrane connected with the end of the vestigial tail; possibly that was the case, but, in *Nyctosaurus* at least, such

an excised membrane would have been little better than none at all.

That the ribs of the abdominal region extended out into the patagial membrane on the sides I have given reasons for elsewhere; I can see no other explanation for their position and lack of curvature in the specimen of *Nyctosaurus* to which I have referred.

THE TERRESTRIAL DEPOSITS OF OWENS VALLEY, CALIFORNIA

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CONTENTS

INTRODUCTION

From September 9 to December 1, 1909, the writer in company with James A. Lane was in the southern half of Owens Valley, California, studying and mapping the general geology in a semi-detailed manner, and gathering data on the terrestrial deposits. The deposits studied particularly lie in the Mt. Whitney Quadrangle of the United States Geological Survey, though work was done in the Olancha Quadrangle, and beyond the limits of both these sheets, as problems demanded. The results of this work are used as a Doctor's thesis in the University of Chicago, this article being one chapter of that thesis.

The purpose of this paper is threefold: (1) to describe the characteristics of the terrestrial deposits of Owens Valley; (2) to discuss the causes and processes involved in their deposition; and (3) to deduce certain criteria whereby materials so deposited may be distinguished from other deposits such as those of lakes and seas, even after cementation has taken place. The adequate study of such deposits should lead to the establishment of criteria by which terrestrial deposits of earlier ages may with certainty be separated from marine deposits. It should also lead to the establishment of criteria for the recognition of various kinds of non-marine deposits. It is recognized that such criteria have already been discussed, and to a certain extent established. But many of these are applicable only to formations of pronounced characteristics, and there are yet many formations of one age and another whose origins are not yet established beyond doubt.

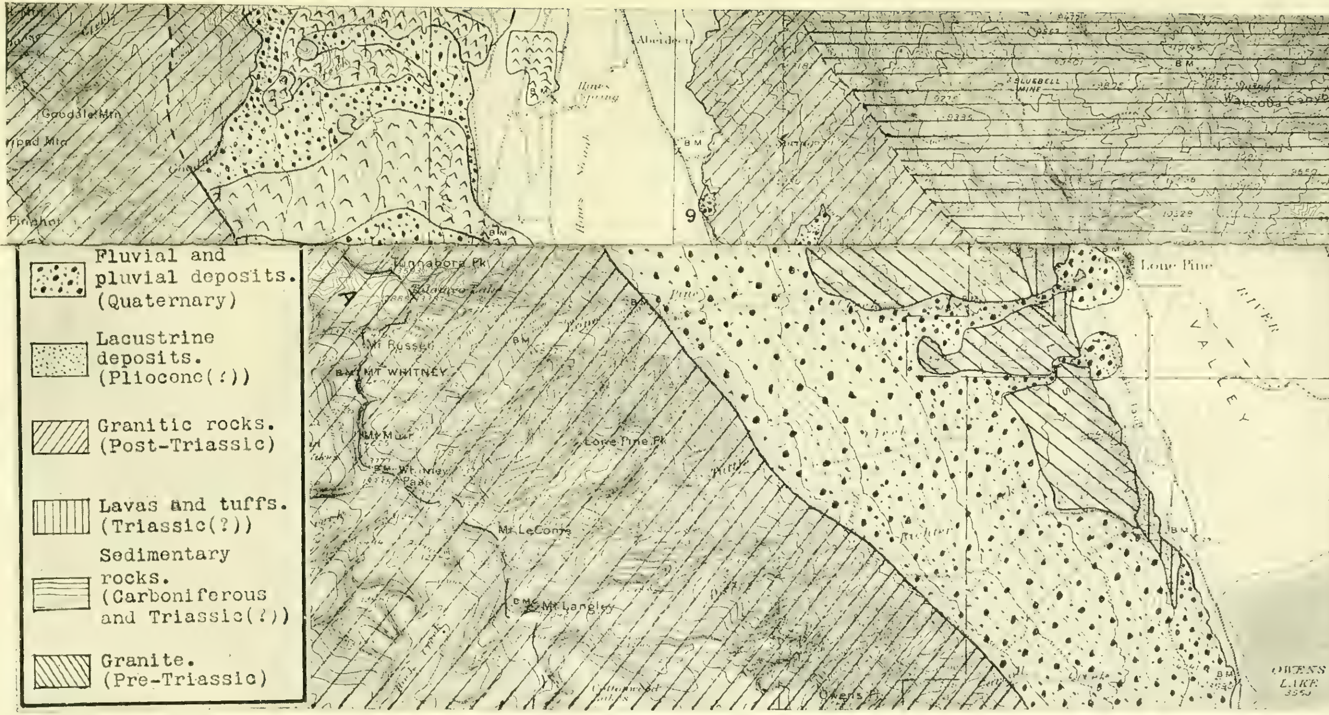
Owens Valley is an area about 100 miles long north and south, by 12–15 miles broad. It is situated in extreme eastern California, about east of a point on the coast midway between San Francisco and Los Angeles. The valley includes the villages of Bishop, Big Pine, Independence, Long Pine, and Keeler, which can be reached by the California and Nevada Narrow Gauge Railroad, connecting with the Southern Pacific at Mina, Nevada.

Physiographically, Owens Valley is located between the Great Basin on the east and the Sierra Nevada Mountain province on the west. The east wall of the valley is the west face of the Inyo Mountains, one of the semi-arid basin ranges, while the west valley

wall is the steep eastern slope of the Sierras. Owens Valley, between these two ranges, is occupied partially by Owens Lake, and drained by Owens River which flows into the north end of the lake. The surface of the valley is broken in several places by the Alabama Hills, Poverty Hills, and a series of recent volcanic cones and lava flows (see Plate I).

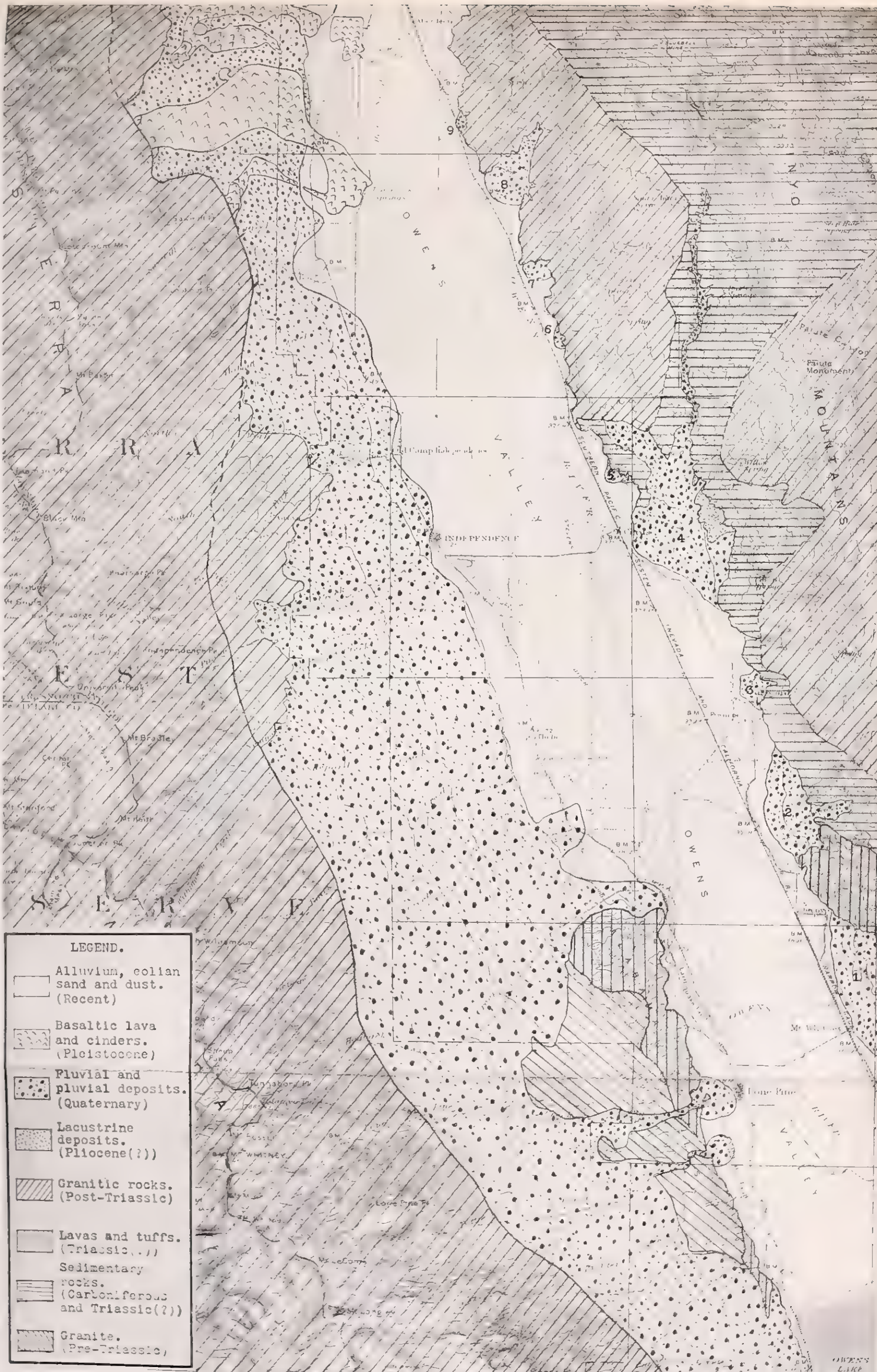
The eastern face of the Sierra Nevada Mountains is a precipitous fault scarp, probably of late Miocene age, attaining a height of 10,000 ft. above the bottom of Owens Valley. In this slope, streams and valley glaciers have carved numerous deep canyons, whose lower portions are choked with drift and whose upper portions are the cirques and bare surfaces of glacially eroded regions. The rock of the mountains in this region is massive, coarse-grained igneous rock, chiefly granite. This rock is weathered chiefly by mechanical processes. Temperature changes and the wedge work of ice cause pieces of rock varying in size from a fraction of an inch to a score or more of feet in diameter to break off and roll down the steep slopes, each piece being broken or worn smaller as it goes. Plants, animals, and ground water are relatively unimportant as weathering agents here, because by reason of the steep slopes, they are not present in abundance. On the other hand, because of these steep slopes, gravity is more than usually important. Oxidation, hydration, carbonation, solution, etc., as usually performed by atmosphere and ground water, do not take place sufficiently rapidly to produce great results on the rocks before these last are disrupted and taken away. That is, the mechanical processes of weathering and transportation take place more rapidly than the chemical processes, and the result is arkose material carried down the mountain canyons and deposited in the valley below. These are the materials to be described as the terrestrial deposits of the valley.

Unlike the Sierras, the Inyo Mountains contain both igneous and sedimentary rock, in about equal abundance. Ordovician, Carboniferous, and Triassic sedimentary formations have been interbedded with Triassic lavas, and intruded by Cretaceous granite and diorite. Though these mountains are not so high by 4,000 ft. as the Sierras, and the slopes are not so steep, still here also mechanical processes of weathering keep ahead of chemical



From Mt. Whitney, Cal., Quadrangle

Scale, about three miles to the inch. Contour interval, 100 feet



FROM MT. WHITNEY, CAL., QUADRANGLE

Scale, about three miles to the inch. Contour interval, 100 feet

processes, this being due partly at least to the fact that the Inyo Mountains receive little precipitation, and the moisture necessary for chemical processes is lacking. Here also canyons have been cut by streams, and material has been transported to the valley and deposited, but unlike those of the Sierras these streams are intermittent, and carry material only after the infrequent rains. The Inyo Mountains have not been glaciated.

The deposits considered in this paper occur along the east foot of the Sierra Mountains on the west side of the valley, and discontinuously along the west front of the Inyo Mountains, which border the valley on the east. The phenomena on the opposite sides of the valley are sufficiently unlike to warrant description separately.

DEPOSITS AT THE BASE OF THE SIERRA MOUNTAINS

LOCATION AND EXTENT

Within the area of the Mt. Whitney Quadrangle, terrestrial deposits at the east base of the Sierra Nevada Mountains cover a belt 1–7 miles wide. In the Olancha Quadrangle to the south, corresponding deposits extend for many miles in a narrow and more or less disconnected belt.

At the north, the plain of the terrestrial deposits is overlain by recent lavas and volcanic cones. Northwest of Owens Lake the alluvial deposits lie against the west edge of the Alabama Hills, and extend around the north and south ends. Two narrow continuations of the deposit extend through gaps in these hills, and deploy slightly on the east side. Elsewhere the plain joins the flat bottom of Owens Valley along a more or less distinct line. On the west side the plain is limited sharply by the foot of the mountains.

In the aggregate, the deposits cover about 175 square miles in the Mt. Whitney and Olancha quadrangles.

TOPOGRAPHY

FANS AND INTER-FAN AREAS

Topographically, this plain of pluvial and fluvial deposits takes the form of a series of fans joined together at their lateral edges. At first glance, either in the field or upon the topographic maps,

it seems to be a continuous plain sloping from the mountains; but studied in detail, it resolves itself into low, gently sloping fans separated by broad, ill-defined, shallow depressions. The fans deploy and become less distinct at a distance from the mountains; the depressions are therefore broader, deeper, and better defined close to the mountains. At its outer edge, the topography of the deposits approaches a plain, in which neither fans nor inter-fan areas can be distinguished.

The axes of the fans are on lines which are continuations of canyons in the mountains; the depressions are between the mouths of the canyons.

From Owens Lake north, the following fans can be distinguished: those of Richter, Tuttle, Lone Pine, Hogback, George, Bairs, Shepard, Pinyon-Pine, Oak, Thibaut, and Sawmill creeks. The last three are small though sharply defined.

A few notes taken north of Lone Pine Creek are here copied, in so far as they refer to the topography of the fans:

> The fan opposite Lone Pine Canyon is sharply set off from the fan of Hogback Creek to the north. Beginning at the mouth of the canyon, it spreads promptly to the north, a distance of about half a mile at the immediate foot of the mountains, and one and one-half miles within a distance of a mile from the mountains. Farther from the mountains, it joins the fans on either side, and its distinctness is there lost. Its north edge is fairly distinct for two miles from the mountains, being markedly higher than the broad, irregular, linear depression between it and the fan of Hogback Creek. This depression is distinct near the mountains, but becomes gradually shallower and narrower away from the mountains, until the two fans coalesce two miles or so out. . . . . From the depression, the slope of the fan of Hogback Creek shows a distinct rise. . . . . The south side of the fan of Shepard Creek is not especially well developed, though it is set off distinctly from the fan to the south. The depression between these two fans is about 200 ft. below their tops, and is one-fourth to one-half a mile broad. . . . . North of the fan of Shepard Creek, the surface declines and does not again reach the high level of this fan as far as the alluvium can be seen.

The streams have a distinct tendency to leave their fans for the depressions between. Shepard Creek now flows in the depression south of its fan. The North Fork and South Fork of Oak Creek have joined in the depression between their respective fans. At some time they were undoubtedly parallel streams. The photo-

graph (Fig. 1) shows the two fans, South Fork flowing in the low place, and North Fork leaving its fan for the depression. This shifting of streams to the inter-fan areas is suggested as a common and efficient process in the tying together of fans, making piedmont alluvial plains, or *bajadas*.[1] By this shifting, fans are made between fans, tying them together and tending toward the union of the fans into one plain.

CHANNELS AND RIDGES

Low ridges and shallow depressions on the individual fans constitute topographic features of a second order. These are the

FIG. 1.—A photograph of the fans of Oak Creek, showing South Fork (*ab*) flowing in the inter-fan depression, and North Fork (*cd*) leaving the fan to join South Fork in the depression.

channels and depositional features of the streams which deposited the fans. The depressions are more noticeable than the ridges.

The depressions are, as a rule, about 10 ft. deep and less than 100 ft. across, though at a maximum they reach a depth of 20–25 ft. and a width of quite 100 ft. Their bottoms are usually flat and their slopes as steep as the material will permit. The elevations are less numerous than the depressions, and have less relief. They are seldom more than 5 ft. above the surrounding plain, and their height in many cases is only equal to the diameter of the individual bowlders of which the ridges are composed. The ridges consist

[1] The term *bajada* has been suggested by C. F. Tolman (*Jour. Geol.*, XVII [1909], 141) to replace the longer term commonly in use. It has the advantage of brevity, but lacks the explanatory value of the older term.

of mere divides between channels and of lines of bowlders bordering the channels.

In keeping with their origin, the depressions and ridges are radiate in their arrangement. At the head of each fan, these features are few; toward the outer edge they are numerous; but at the extreme edge they are again rare. Three miles from the edge there are probably 50 channels, for one close to the head, and something like that proportion between the same three miles from the edge and the outer edge itself. Channels which, near the head of the fan, are close together, diverge outward, and each may break up into other channels, each less deep and less broad than the one from which it springs. Quite commonly these channels lead to depressions between fans and disappear.

It is clear that these channels on the fans mark the courses of the distributaries from the fan-making streams. The streams branched again and again, some of the distributaries reaching the inter-fan depressions and flowing off through them. It is equally clear that some of the elevations are merely inter-distributary divides. The origin of the ridges bordering the depressions is not so clear. Possibly they are in principle natural levees, built as the waters overflowed their channels. It is understood that these are the streams which deposited last on the surface of the fans. In the building of the bajada, the channels undoubtedly shifted frequently, those of one time being filled up and a new set formed during periods of greater deposition following heavy rains or the rapid melting of snow in the mountains.

THE STREAM CANYONS

The streams of the bajada do not now distribute over the fans, but flow in deep, steep-sided, canyon-like valleys; that is, the bajada is being dissected (Fig. 2). This is true to a greater or less extent of all the streams which have played a part in the deposition of the plain.

The canyons in the bajada vary in depth from 20 ft. to 250 ft., and average about 200 ft. in width. The depth is determined by the size of the stream, the height of the fan, and the position of the stream on the fan. The most pronounced canyons are those of

Carroll and Lone Pine creeks, which are large streams flowing in the high central part of well-developed fans. Carroll Creek canyon is 250 ft. deep at the head of the fan, and shallows to less than 50 ft. at the edge of the bajada. Shepard Creek is almost as large as either of the two streams previously mentioned, but it flows on the side of its fan, where the surface and gradient are lower, and its canyon is only 30 ft. deep. Hogback Creek has cut deeply at the head of its fan, but farther out, where the stream has shifted to the side, there is little intrenchment.

FIG. 2.—The canyon of Carroll Creek in the Sierra bajada. The dark strip consists of trees 20 ft. bigh.

These canyons are the most conspicuous topographic features of the bajada. They clearly follow the building of the bajada, and were excavated under different conditions. They therefore have both an expository and a historical value. Problems connected with them will be discussed later.

BOWLDER BELTS

A fourth topographic feature of the bajada consists of almost innumerable lines of bowlders which, though primarily a matter of the constitution of the bajada, affect the topography in a minor way.

These lines of bowlders have a radiate arrangement similar to that of the channels and ridges. The bowlders are so close together

as to make low and discontinuous ridges, which by winding his way among the bowlders one may in some instances be able to cross without climbing. The height of the ridges is determined by the size of the bowlders, and is usually less than 10 ft. They seldom consist of more than two thicknesses of bowlders.

THE SLOPE OF THE BAJADA

The slope of the piedmont plain away from the mountains varies rather uniformly with distance from the mountains. It also varies

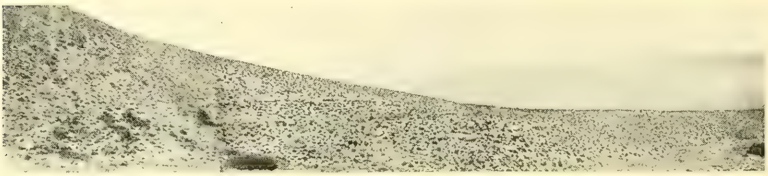


FIG. 3.—The slope of the Sierra bajada as seen on the north wall of the canyon of Carroll Creek.

FIG. 4.—The slope of the Sierra bajada on the south wall of the canyon of Carroll Creek.

irregularly from place to place along the foot of the mountains. Along Carroll Creek the slope at the face of the mountain is 18° and 20° (Figs. 3 and 4). Where it is 20°, the angle decreases to about 12° a quarter of a mile from the mountains; and where it is 18° at the mountains, the slope is 6–8° a mile or so out. The fan of Lone Pine Creek has a slope of 6° at the mountains, which decreases almost uniformly to a very low slope at the west edge of the Alabama Hills. The difference between the slopes of the fans of Lone Pine Creek and Carroll Creek might be due to a diastrophic tilting, which either did not occur at Lone Pine Creek or did not

affect the fan there. However, no other evidence of diastrophism appears at Carroll Creek. Probably the difference is due to variations in the gradient and size of the two streams in the mountain canyons, at the time the fans were built. The *average* slope of the fans in the valley at the base of the mountains is about that of the fan of Lone Pine Creek, 6°. The slope is greater along the axes of the fans than in the inter-fan depressions.

MATERIALS

The material of the Sierra bajada is not well exposed, but some idea of its upper portion can be obtained. Nothing is known of

FIG. 5.—The largest bowlder seen in the Sierra bajada. The man is 6 ft. tall. This bowlder lies in the yard of the Cerro Gordo power shanty in Lone Pine Canyon, $1\frac{1}{2}$ miles from the foot of the mountains.

that portion lower than 300 ft. from the surface, as there are no cuts so deep, and well-records are lacking. The material may be seen in three sets of places: (1) on the unaltered surface of the plain, (2) on the sides of the shallow channels, and (3) in the walls of the canyons.

Lithologically, the bajada is composed of material from the granitic rocks of the Sierras, disintegrated rather than decomposed. Its components are bits of granite, rather than crystals of quartz or feldspar. Even the disintegration is not complete, for the material is commonly coarse. It is clear that the source of the material is the mountains, and that it was removed from the parent ledges mechanically, and transported to its present position by streams,

aided in the upper parts of the canyons by glaciers. There is every evidence of immature weathering of the materials. At the time the fans were being deposited, the mechanical processes of weathering greatly exceeded the chemical, and transportation was free and rapid.

TEXTURE

The fans contain all textural grades from pieces the size of small sand grains and even clay particles, to bowlders more than 20 ft. in diameter, but pieces less than an inch in diameter predominate.

The most striking and surprising feature of these fans is the extreme coarseness of *some* of its materials. Innumerable large

FIG. 6.—Bowlders on the surface of the Sierra bajada. Their size may be estimated from the horse. Picture taken on the fan of Sawmill Creek about a mile from the foot of the mountains.

and small bowlders appear on its surface, on the sides of the shallow channels, and on the walls and floors of the canyons. On the unaltered surface, they occur in radiating lines and belts, roughly parallel with the radiating channels. They are practically confined to the higher parts of the surface, where the main streams flowed. None appears in the inter-fan depressions. More bowlders are scattered near the heads of the fans than toward the outer edges but they are not noticeably larger here. They are arranged in belts or low ridges along the borders of the shallow channels and are scattered more sparsely on the side slopes. Bowlders are numerous on the walls and bottoms of the canyons, but without definite arrangement. The beds of the streams are everywhere choked with them, and they occur in and along the braided channels

used by the streams in time of flood. Their unusual abundance in the canyons is doubtless due to the bowlders having been sorted out in the process of canyon-cutting, the finer material being carried on and the coarse left.

The whole surface of the bajada considered, the average diameter of the bowlders is perhaps about 2 ft. but those 8 ft. in diameter are by no means uncommon. The largest seen are a mile west of Lone Pine, 6 miles from the mountains, and at the Cerro Gordo power shanty, on Lone Pine Creek, $1\frac{1}{2}$ miles from the mountains.

Fig. 7.—The canyon of Lone Pine Creek in the Sierra bajada. Bowlders appear almost as large as the two-story house.

The one west of Lone Pine is $10 \times 20 \times 30$ ft. above ground. The size of the one at the shanty is shown in Fig. 5, the man being 6 ft. tall. With these exceptional bowlders are thousands of others as large as 10 ft. in diameter, as can be seen from Fig. 7. The size and distribution of this coarse material may be seen further in Figs. 6 and 7. Fine material in the bajada is shown in Fig. 8.

STRUCTURE

Owing to the scarcity of good exposures, the structure of the materials of the Sierra bajada is not readily determined. The only satisfactory exposure is near the mountains on Lone Pine Creek (Fig. 9). Because the canyon walls never stand in vertical bases, but slump down readily to gentle slopes, they show the

texture only, not the structure. The relations of coarse and fine material can be seen to some extent on the surface of the plain.

As has been shown above, the coarse and fine materials are more or less separated on the surface of the plain. There are considerable stretches, usually the lower areas, where the surface material is all fine. Such areas are interrupted by narrow belts of large bowlders. If the structure of the whole plain were judged by its

Fig. 8.—Fine material in the Sierra bajada seven miles from the mountains

surficial aspect, the material could be known to be roughly sorted into many narrow radiating belts of coarse materials, and broader belts of fine materials. Presumably these lines would not have the same position horizontally for any considerable vertical section, as the stream channels undoubtedly shifted and distributed often.

So far as cuts in the bajada show, the materials consist of a mixture of large blocks of granite, bowlders not so large, angular fragments the size of cobbles, tiny angular bits of rock, sand, and clay. Where any considerable vertical section is seen, these different grades are sorted into indefinite lenses and pockets. There are no definite layers of great extent. Divisions of material are nowhere seen to be continuous for as much as 100 ft. Some small

exposures show material which is apparently unstratified. Even where sorted into lenses or irregular areas, there is a considerable mixture of all sorts of material in each division, each merely averaging a little coarser or a little finer than its surroundings.

All materials are clearly water laid, but under conditions which allowed of very poor sorting.

The structure and texture of the materials are brought out best by detailed descriptions and photographs. Such illustrations are given below and in Figs. 9, 10, 11, 12, and 13.

FIG. 9.—A section in the Sierra bajada from the south wall of Lone Pine Canyon, $\frac{1}{2}$ mile west of the Cerro Gordo power shanty.

1. Two hundred to three hundred yards above the power shanty on the south wall of the valley of Lone Pine Creek, wash and gravity have exposed the material almost continuously for a distance of about 100 ft. vertically. The section consists of both fine and coarse material roughly separated from one another. There are two horizons of coarse bowlders, one 20 ft. from the top and the other about 30 ft. from the bottom. In the upper horizon the bowlders are fairly well rounded, and range up to 4 ft. in diameter, the average being about 1 ft. In the lower zone of bowlders there is greater range in size. There are numerous pieces 6 in. through, and several 6 ft. or so in diameter. The sorting is very slight. Between these two horizons the materials are mostly fine, though large bowlders are not entirely absent. Immediately above the

lower zone of bowlders is a fairly well-defined bed of gravel, the constituents of which average 3–4 in. in diameter. Between this gravel layer and the upper zone of bowlders, the material differs in different parts of the cut, the structure being decidedly pockety. In one place the fine gravels grade into the coarse bowlders above; in another, there is a body of clay between the two; in another, the gravel layer does not appear, and clay separates the two beds of bowlders (Fig. 9).

2. A six-foot cut a mile from the mountains shows a matrix of clay and sand in which there are angular fragments averaging

FIG. 10.—Roughly sorted materials of the Sierra bajada on George Creek

10 in. through, with occasional bowlders 3 ft. in diameter. The bowlders are angular or subangular, and none are well rounded. They are not abundant enough to touch one another. There is apparently no sorting.

3. A hundred yards above the last section, the material is rudely but distinctly sorted. At the bottom there is a fairly uniform layer of angular gravel, averaging 4 ft. in thickness, of which the upper $1\frac{1}{2}$ ft. give place at the east end to a projection downward of a pocket from the coarse layer above. There is little clay in the cut, and the fragments of rock are abundant enough to touch one another. The pores are filled with coarse, arkose sand, loosely packed.

4. The last section gives place, within a few feet, to unsorted material entirely similar to that of section 2. From here to the mountains the sorted and unsorted materials occur with about

equal frequency, in the same position relative to the stream and to the surface of the fan.

5. Material is exposed on the Mt. Whitney trail through the Alabama Hills. It is composed of rounded or partly rounded granitic bowlders, up to a foot in diameter, with a sparse matrix of granitic pebbles. Though stratification is not apparent, all material is clearly water laid (Fig. 12).

6. On Dietz Creek, just above its junction with Tuttle Creek, material is exposed. It is a mixture of very fine angular fragments

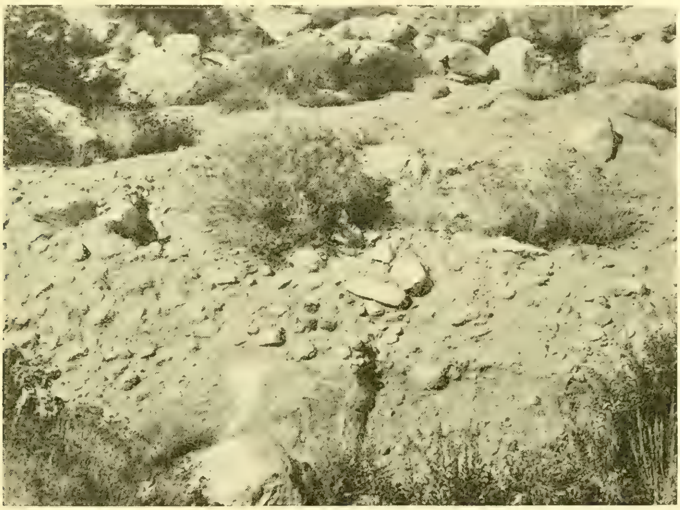


FIG. 11.—Unstratified material on George Creek. This section occurs within only a few feet of that shown in Fig. 10.

with material having the texture of coarse sand. The fragments are not so angular as pieces just broken by weathering. They seldom exceed a half-inch in diameter, and the average is about $\frac{1}{16}$ of an inch. The finer material consists of arkose, flakes of mica, grains of pyrite, and of ferro-magnesian minerals, being almost as common as quartz. The coarse and fine materials are unassorted.

From these descriptions and photographs, the following characteristics of the materials are shown:

1. The material was derived from the rock of the Sierra Nevada Mountains.

2. It is the result of immature weathering in the mountains.

3. In texture the materials range from clay-like particles, to bowlders 30 ft. in diameter.

4. Some of the large bowlders are ice-shaped, and some have been shaped slightly by water.

5. Stratified, partly stratified, and entirely unassorted materials occur in something like equal proportions.

6. Where stratification exists, the materials are sorted into lenses and pockets, never into uniform, continuous layers.

FIG. 12.—A pocket of stratified gravel in the Sierra bajada seven miles from the mountains on Lone Pine Creek.

7. The materials become gradually finer as distance from the mountains becomes greater, at least so far as sub-surface material is concerned.

8. No fossils were found in the material.

These features will be discussed after the deposits at the foot of the Inyo Mountains have been described.

TERRESTRIAL DEPOSITS OF THE INYO MOUNTAINS

Terrestrial deposits are represented in the Inyo Mountains by two distinct types of materials of two distinct ages. They will therefore be discussed separately.

PLIOCENE LACUSTRINE DEPOSITS

No description of the terrestrial deposits of Owens Valley, and no discussion of the older deposits at the foot of the Inyo Mountains would be adequate without mention of certain lacustrine clays and

sands in Waucobi Canyon, described by Walcott,[1] and in the vicinity of Haiwee described by Turner,[2] Fairbanks,[3] and Campbell,[4] even though such mention leads beyond the confines of the Inyo Mountains. Both these deposits were seen by the writer, and they are here discussed in so far as they may be used as a type of lacustrine deposits. Walcott[5] and Spurr[6] have interpreted these deposits in slightly different ways, but both agree that they are lake deposits, and as such they will be described. Discussion as to whether they record great recent uplift of the Inyo Mountains, as according to

FIG. 13.—Unsorted material of the Sierra bajada

Walcott, or were deposited in a deep, widely distributed lake, as Spurr contends, is not in place here, though such discussion is given in the unpublished part of the thesis.

LAKE BEDS IN WAUCOBI CANYON

Waucobi Canyon, or the Waucobi embayment as it is called by Walcott, is a re-entrant in the west face of the Inyo Mountains a few miles north of the boundary of the Mt. Whitney Quadrangle

[1] C. D. Walcott, *Jour. Geol.*, V, 240–48.

[2] Personal communication to Spurr.

[3] H. W. Fairbanks, *Am. Geol.*, XVII, 69.

[4] M. R. Campbell, *Bull. U.S. Geol. Surv. No. 200*, p. 20.

[5] *Jour. Geol.* V, 344–48.

[6] J. E. Spurr, *Bull. U.S. Geol. Surv. No. 208*, pp. 209–10.

east of Alvord. In this re-entrant are a series of unconsolidated and partly consolidated sands, clays, and gravels. They were traced from wall to wall of the re-entrant, and up the canyon for some $3\frac{1}{2}$ miles. Mr. Walcott reports their continuation almost to the crest of the mountains.

There are two more or less distinct phases of this deposit. Near the north and south walls of the re-entrant are interbedded clays, limestones, and conglomerates. These materials are mostly sorted into distinct beds, but are locally arranged in pockets or irregular

FIG. 14.—Lacustrine limestones and conglomerates, deposited near shore in the Waucobi embayment.

areas, when seen in sections. Two miles east by northeast of Alvord, a ledge of limestone and conglomerate outcrops under a low hill of angular alluvium. The limestone is white, porous, earthy, and filled with small fossils of gastropods. Other rock has a matrix of calcium carbonate, but contains enough pebbles to make it conglomeratic, though the pebbles are seldom in contact. The stony matter is fairly well rounded. In size its pieces reach 6 in. in diameter, though the average is about 1 in. The pebbles are mostly of sedimentary rock, but with some granites. All the material is local.

A series of exposures along the main road $1\frac{1}{2}$ miles southeast of the fruit ranch of J. S. Graham, at the southeast margin of the re-entrant, shows well the constitution of the beds. All the material is irregularly sorted. In some places it is of light-yellowish

clay, which contains enough lenses and pockets to give it a bedded aspect. In other places it is made up of alternating layers of gravel and clay, the latter containing bowlders in many places (Fig. 14).

Just below these coarse, roughly sorted materials on the main road, the constitution changes abruptly to sandy clay, arranged in continuous, uniform, apparently horizontal layers. The change from coarse, poorly sorted conglomerates to fine clays takes place within 500 ft. These clays appear all the way to the mouth of the

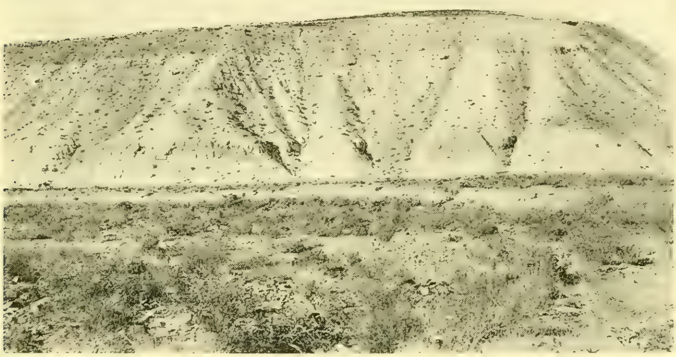


FIG. 15.—Lacustrine sand and clay in the Waucobi embayment. The layers are continuous and of uniform thickness.

canyon, as erosional hills about 100 ft. high, and in the valley walls. Most of the clay is fine, becoming white dust when powdered. Some layers are sandy and some calcareous. They are not usually firmly cemented. Layers 1–10 ft. in thickness can be traced continuously along the hills (Fig. 15).

These are doubtless lake deposits, the coarser marginal conglomerates being the littoral phase, and the centrally located clays and sands having been deposited in quieter, deeper water, farther from shore. The fossils have been determined by Dr. Dall as Pliocene to recent. As the beds lie unconformably under Quaternary alluvium, they are probably Pliocene or early Quaternary in age.

LAKE BEDS NEAR HAIWEE

Toward the south end of Owens Valley, in the vicinity of Haiwee post-office, there is a series of calcareous and arenaceous lake beds. They were seen by the writer $\frac{1}{2}$ mile southwest, 1 mile east, and $\frac{3}{4}$ mile northwest of the post-office. They are fine, white, and distinctly bedded. East of the post-office, the beds dip 8° to the northwest. Northwest of the post-office they dip 14° north. They were best seen $\frac{3}{4}$ mile northwest of the post-office, where a hill 175 ft. exposes them from top to bottom. They consist of light-colored, siliceous

FIG. 16.—Unconformity between Quaternary conglomerates and Pliocene lake beds north of Haiwee. Some of the bowlders of the conglomerate are composed of the underlying clays.

fine clays or shales. In the lower part of the exposure numerous small flat bodies of gypsum occur. Most of the plates lie parallel with the beds, but in some places they appear as secondary bodies along joints and faults.

The lake beds here are covered with a hard, coarse conglomerate derived from the Coso Mountains to the east. The lake beds and conglomerates are unconformable. The conglomerate lies on the very irregular surface of the truncated edges of the dipping beds of clay, the surface between the two having a relief of about 15 ft. (Fig. 16). The constituents of the conglomerate are chiefly granite, sedimentary rock, and scoriaceous basalt, but near the contact many large fragments of the underlying clays are also included. The

conglomerates must be as old as the early Quaternary. The hill on which they occur is far from the Coso Mountains and separated from them by numerous valleys, similar hills, and more lake beds. The lake beds are then pre-Quaternary, probably Pliocene, and correlated with the similar beds in Waucobi Canyon. No fossils were found here.

OLDER DEPOSITS AT THE FOOT OF THE INYO MOUNTAINS

Bearing in mind the main characteristics of the deposits described above, and accepting the idea of their lacustrine origin, as we are apparently forced to do, we can proceed to a description

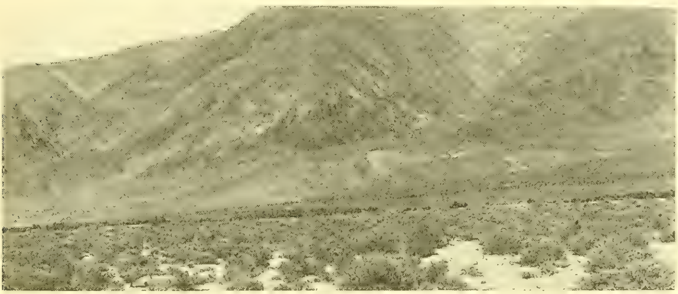


FIG. 17.—Low hills of old deposits surrounded by present-day fans, northeast of Mt. Whitney station.

and interpretation of the older deposits of terrestrial material at disconnected points along the foot of the Inyo Mountains.

Distribution as indication of age.—At several places, most notably northeast of Mt. Whitney station and east of Citrus, hills of terrestrial material rise 100 ft. above fans which are now in process of making about them. The materials of the hills differ from those of the fans in texture, and in the fact that they are cemented.

Along the west face of the mountains immediately northeast of Mt. Whitney station, an exceptional series of events is recorded by the nature and relations of the alluvial deposits. Two hills, 100 ft. or more in height, occur half a mile apart, and half a mile from the foot of the mountains. Between and around these hills the lower surface is covered with the typical alluvium of the region. The hills themselves are of gravel and sand. Evidently a great

deposit was laid down here, its remnants being represented by the hills. Conditions changed so that erosion took place, the old deposit being dissected into hills and valleys. Later, as the streams were brought to adjustment again, they deposited new fans among the remnants of the old deposit (Fig. 17).

Due east of Citrus, a series of low spurs projects from the foot of the mountains into Owens Valley. At the foot of the mountains they stand 50–75 ft. above the plain, and become gradually lower westward. They are not in direct contact with the present fans, though fans occur at lower levels north and south of them. These projections are not at the mouths of present canyons (Figs. 18 and 19).

FIG. 18.—Lacustrine beds (light colored) lying against rocks of the Inyo Mountains (darker rock to the right), east of Citrus. Stratification may be seen in the left center.

The deposits in Mazourka Canyon, the canyon east of Aberdeen, and on the flanks of the mountains east of Keeler should also be included in this category. In the two canyons, older cemented gravels occur as distinct, flat-topped, but eroded terraces, 50 ft. above the stream beds. East of Keeler, hills of conglomerate rise 200 ft. above present alluvial surfaces.

Constitution.—The materials of the older deposit at the foot of the Inyos differ from those of the Sierra bajada in various ways; especially in (1) lithological composition, (2) texture and shape of pieces, (3) structure, (4) cementation.

1. This deposit is made up of fragments of all rocks occurring in the Inyo Mountains, from which they are derived, including both igneous and sedimentary rocks.

2. The constituents have not a great range in size. In place of large bowlders, the coarser materials are large-sized cobbles or very small bowlders. Texturally, the fine material is sand or clay. The average size of particles is probably less than half an inch in diameter. Bowlders even as large as 1 ft. in diameter are wanting.

In the Sierra bajada the pieces of rock are either ice-shaped, or they are almost as angular as when broken off by weathering. Here the effects of glaciation are not seen. The fragments have been worn to pebbles, few sharp or irregular edges appearing.

FIG. 19.—Close view of the older deposits east of Citrus. Note the layered structure and the dip of the beds.

They are in general well rounded, having been shaped by the action of water.

3. These materials are arranged in definite, continuous layers of gravel and sand. The layers can be traced the whole length of the various outcrops as beds of nearly uniform thickness. East of Citrus a definite, continuous layer of clean, fine gravel, uniformly 2 ft. thick, overlies a layer which is a mixture of small angular fragments, sand, and clay. Northeast of Mt. Whitney station the talus from a deep cut is of uniform-sized cobbles and sand. The stratification of this material may be seen in Figs. 18 and 19.

Wherever exposures were seen east of Citrus, the beds have an appreciable westward dip (away from the mountains). Clinometer readings vary between 8° and 18°. The *direction* of dip is nearly

constant. No faults, minor folds, or other evidences of diastrophism were seen. This dip may be depositional, or the beds may have been tilted to their present position by an uplift in the mountains. Eighteen degrees is a high dip to be considered depositional when the material is fine.

4. The older deposit shows a tendency toward cementation, and some layers are firmly cemented. In general it is the layers of coarse material, originally more porous, that are cemented.

In the beds east of Citrus mentioned under (3) above, the upper layer of gravel is cemented to firm conglomerate. It is so solid as to ring under the hammer and to need more than one hard stroke

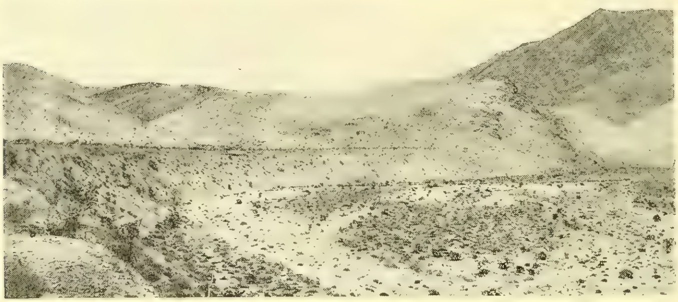


FIG. 20.—A stream terrace of older alluvium in Mazourka Canyon

before it is broken. The material of the finer layer below cannot be picked out by the hand, but yields readily to the hammer. The gravel layers are almost everywhere so indurated that they stand out conspicuously, the determination of dips thus being made easy.

The above characteristics hold for all the deposits of older materials at the foot of the mountains, with the exception of those in Mazourka Canyon. The deposits in this canyon belong to the older deposit, for they occur in terraces above the present depositional surfaces, but the materials are in some respects different. Areally considered they take the form of the canyon in which they were deposited, and thus occur in a long strip. They constitute more or less definite stream terraces on the sides of the present valley (Fig. 20). Texturally they are like the deposits along the foot of the mountains, the chief difference being in the strati-

fication. Instead of being in definite layers, as are the deposits at the foot of the mountains, the materials in the canyon are in indefinite lenses and pockets, similar to those of the Sierra bajada, though on a much smaller scale.

An examination of two detailed sections noted just above Barrell Springs brings out the difference between these deposits and those east of Citrus and Mt. Whitney station:

1.

$1\frac{1}{2}$ ft.......	Angular fragments the size of cobble, and clay.
1 ft.......	Well-sorted, very fine gravel. Pinches out in both directions.
$1\frac{1}{2}$ ft.......	Mixture of cobbles and clay. Pinches out upstream.
$1\frac{1}{2}$ ft.......	Clay with some small angular bits of rock.
1 ft.......	Well-sorted, loose, fairly well-rounded cobbles; average size $1\frac{1}{2}$ in.; one-inch clay layer in middle.
3 ft.......	Mixture of sand, clay, and gravel; little or no stratification; pockety; contains one bowlder one foot in diameter.
$2\frac{1}{2}$ ft.......	Clay, sand, some gravel; poorly sorted.
$2\frac{1}{2}$ ft.......	Fine angular fragments; little or no clay or sand; well assorted.

2. Fifty feet down the valley from the last, the following section occurs:

3 ft.......	Mixture of coarse and fine angular gravel, with clay in the interstices; average size of constituents 1 in. in diameter; occasional bowlders 1 ft. in diameter.
1 ft.......	Moderately fine gravel; little or no clay; no pieces larger than 3 in. in diameter; pinches out in 12 ft. up valley.
2 ft.......	Clay and pebbles intermixed; rude layer of cobbles in middle.
$2\frac{1}{2}$ ft.......	Fairly well-sorted gravel, coarser at bottom. Pinches out rapidly in both directions. Loosely packed, interstices not filled.
3 ft.......	Irregularly bedded bowlders, cobbles, fine gravel, clay.
2 ft.......	Indefinitely bedded fine angular gravel. Average $\frac{1}{2}$ in. in diameter.
1 ft.......	Pockety, coarse gravel, constituents up to 10 in. in diameter.

In both sections, the materials are slightly cemented. Not a single subdivision of one could be traced 50 ft. to the other. For further details of these materials see Figs. 21 and 22.

It is thus seen that the materials of Mazourka Canyon differ from the rest of the older deposit at the foot of the mountains in

that it includes coarser materials and has a lens and pocket structure (cf. Figs. 19 and 21).

Origin of the older deposit at the foot of the Inyos.—It will be seen from the foregoing that most of the older deposit is sufficiently unlike the Sierra bajada to lead one to conclude that its mode or conditions of origin were not the same. On the other hand, if it be compared with the near-shore phase of the lake beds in Waucobi Canyon, a strong resemblance will be seen: (1) Both deposits

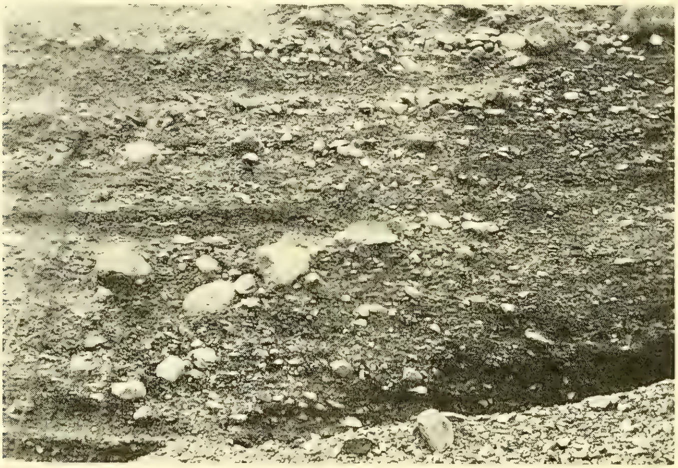


FIG. 21.—Stream deposit in Mazourka Canyon. Compare with Figs. 14 and 15

were formed and eroded before the deposition of the recent alluvium. (2) Both are firmly cemented, at least locally. (3) They are similar in texture, both being fine and having a low textural range. (4) Their stratification is the same, both being sorted into layers. They are dissimilar in that the constituents of the deposits at the foot of the mountains are better rounded than those in Waucobi Canyon, and the former contain no fossils. With such similarities between these deposits and the lake beds, it seems clear that the older materials northeast of Mt. Whitney station and east of Citrus are of lacustrine origin, and belong to the same formation as the lake beds in Waucobi Canyon and at Haiwee. If so, the lake in which they were deposited was shallow, and the shore lay against the

mountains immediately to the east. The dissection of the deposit probably took place subsequent to the uplift of the mountains and the draining of the lake. If lacustrine beds corresponding to them were deposited at the foot of the Sierras, they have been covered and concealed by the more recent alluvium.

The deposits in Mazourka Canyon are obviously not lacustrine, but of stream origin. They were probably laid down on the floor of a mature valley, which was tributary to the lake east of Citrus.

FIG. 22.—Photograph to show the shapes of the cobble in the terrace of Mazourka Canyon.

The differences between these deposits and those along the foot of the mountains may be taken as differences characteristic of lacustrine and fluvial deposits.

THE PRESENT FANS

DISTRIBUTION

Between Mt. Whitney station and Aberdeen there are nine separate fans at the foot of the Inyo Mountains. On the map (Plate I) they are numbered 1 to 9, beginning at the south. Of the nine fans, 1, 2, 4, and 8 are large, each covering more than a square mile, and 3, 5, 6, and 9 are smaller. All of them occur at the mouths of mountain canyons. The largest one, No. 4, is at the mouth of the largest canyon, Mazourka, though it is not so well shaped as the others. Between the mouths of the main canyons and between the main fans are some patches of alluvium too small to map and not important in any way. These patches occur at the lower ends

of very small valleys. Fans also occur along the mountains outside the mapped area. They were seen northeast of Aberdeen and at Keeler.

SHAPE AND TOPOGRAPHY

In general there are two controlling factors in the shapes of the fans. At their mountainward edges they are confined by the walls of the mouths of the canyons, from which they take their form. Their outer edges deploy slightly on the plain. Nos. 2 and 8 extend about a mile into their canyons, and No. 4 extends still farther up Mazourka Canyon. Nos. 1 and 3 show deployment on the plain. No. 2 is made up of two smaller fans, with a depression at their junction.

The surfaces of these fans are very similar to the surface of the Sierra bajada, except that all features are on a smaller scale, the fans, except No. 2, are simpler and remain separate, and these fans are not now in process of dissection. The individual fans show numerous radiating channels and low ridges similar to those on the Sierra plain, but they give the surface here a relief of no more than 7 or 8 ft. at a maximum. The ridges are almost invariably belts of bowlders. The fans are not dissected as is the Sierra bajada. The streams still flow on the surface in the radiating channels, but they flow only after the infrequent rains in the mountains.

The slope of the fans varies considerably from head to outer edge. Fan No. 8 has a slope of about 10° at its head, 5–6° midway of its length east and west, and approaches flatness at its outer edge. Fan No. 1 has a slope of more than 600 ft. per mile in its upper part. The upper part of fan No. 2 slopes westward 800 ft. in a mile. This is steeper than the average.

MATERIALS

These fans at the foot of the Inyo Mountains have not been dissected, and exposures of the material are therefore few and shallow. Some data can be collected from surface materials, there are a few shallow cuts along the channels, and one prospect pit affords a good exposure.

Each fan is made up of pieces of the kind of rock in which the canyon back of it is cut. For instance, 99 per cent of the material

of fan No. 8 is granite, the other 1 per cent scoriaceous lava and slate. All the face of the mountains here is granite, which is bordered along the edge of the Santa Anita flat by slate. Lee[1] maps a volcanic mountain southeast of Aberdeen, which doubtless explains the occasional fragments of scoriae. The fan northeast of Aberdeen is composed of bits of granite, gneiss, scoriaceous basalt, and limestone. All these rocks occur together in the walls of the canyon. Fan No. 1 is made up largely of bits of lava, sedimentary rock, and granite. No. 2 is mostly of sedimentary rock and lava,

FIG. 23.—Bowlders on the surface of fan No. 8 north of Citrus. Their size may be estimated.

with some fragments of granite. No. 3 contains a mixture of sedimentary rock, diorite, and granite, in keeping with the rocks east of it.

On the surface of the fans there are both coarse and fine materials arranged as on the Sierra bajada in diverging lines or belts from the head of the fan.

Though the bowlders are not so large as on the opposite side of the valley, they are still astonishingly large for the drainage by which they were transported. The largest bowlders seen were near the head of fan No. 8, where there are some 10–12 ft. in diameter. On fan No. 2 bowlders are especially numerous. Toward

[1] W. T. Lee, *Water Supply and Irrigation Paper, U.S. Geol. Surv., No. 181*, Pl. I.

the head of the main fan the entire surface is so covered with them that a horse cannot travel over it. The average size of the bowlders is about $1\frac{1}{2}$ ft. Their number and size can be seen in Fig. 23. The photograph was taken from fan No. 8.

These bowlders show little shaping. If fragments were broken from ledges by the wedge work of ice and gravity, and then the sharp and irregular edges dulled during a short period of transportation, their present shape would result. Neither glaciation nor prolonged rolling has affected them.

FIG. 24.—Angular material in the fans at the foot of the Inyo Mountains

The fine material on the surface of the fans occurs in largest areas near the outer edges, where there are few bowlders, and the surface material has about the texture of fine gravel or coarse sand. A half-mile from the edge it is made of fragments more or less shaped by transportation, averaging perhaps 3 in. through, with some lines of larger bowlders. At the head the surface is practically covered with bowlders.

Although exposures of material beneath the surface are almost wanting, a few shallow cuts were seen. The data they afford follow:

1. In the outer edge of fan No. 8, 4 miles south of Aberdeen, is a pit dug as a placer prospect, 10 ft. deep, 15 ft. long, and 5 ft. wide. The material is all fine, there being nothing as large

as 1 in. in diameter. The pieces are distinctly angular. The section follows:

3 ft......Fine clay and gravel, not laminated.
1 ft......clay
2 ft......fine gravel
$\frac{1}{2}$ in......clay
3 ft......fine gravel
2 in......clay

2. Ten feet of material are exposed in the fan northeast of Aberdeen. It is not stratified. Angular bowlders are imbedded in a matrix of clay.

3. Near the upper end of fan No. 2, a gully affords an exposure. The section consists of both stratified and unstratified material. In the unstratified parts, the main constituent is clay, in which are imbedded numerous angular bowlders. One $3\frac{1}{2}$ ft. in diameter occurs in a mass of clay.

4. Distinctly angular alluvium is shown in Fig. 24.

SUMMARY

It is apparent from the foregoing that there are two sorts of terrestrial deposits in and at the foot of the Inyo Mountains, of two distinct ages. The first deposits appear to have been made when the mountains were low and bordered by a lake. Mazourka Canyon had been cut and brought to grade, deposition taking place in its bottom from its mouth up. The deposits of the time are all fine, fairly well sorted in Mazourka Canyon, and very well sorted in Waucobi Canyon and along the mountain foot.

Conditions so changed that these first deposits were largely removed by erosion. The change was probably brought about by the uplift of the mountains, as the later alluvium is much coarser than the older. After the uplift, new canyons were cut in the mountains, and new fans deposited among the remnants of the old lacustrine deposits. This process is still going on.

SOME PROBLEMS OF THE TERRESTRIAL DEPOSITS

The fluvial deposits of Owens Valley, as described above, offer several problems. In some cases the solutions of the problems are simple and obviously correct; in others the solution is not so clear,

and there is some doubt as to the correctness of tentative conclusions; in still other cases, the solution is entirely hypothetical. In some cases various lines of explanations may have partial application to the observed features. These problems are here discussed individually.

MANNER OF FORMATION OF THE FANS AND BAJADA

CAUSES OF DEPOSITION

Material was deposited at the foot of the Sierra and Inyo mountains, primarily because of an abrupt decrease in the gradient of the streams. When the mountains were first uplifted, and precipitation fell on the slopes, streams formed and flowed swiftly down the sides, carrying material from their channels. When the base of the mountains was reached, the carrying power was suddenly and greatly decreased, and the first deposition resulted.

Once started, other factors tended to increase the process of deposition. Streams lost volume by sinking into loose material. This not only reduced the volume of the transporting agent, but also lessened the velocity of the water remaining at the surface; both these changes caused deposition.

The average relative humidity of the Sierra Nevada Mountains is not far from 60 per cent, and that of Owens Valley probably not more than 40 per cent.[1] When the streams reach the plain, evaporation is increased; hence loss of volume, loss of velocity, and decrease in carrying power. This would not be so important in the case of the Inyo Mountains, because the difference in humidity between mountains and plains is not so great there. However what little rain falls, is in the mountains rather than on the plains, and evaporation takes place more rapidly in the latter locality.

Water taken from streams by irrigation so decreases their volume in some other localities as to aid in causing deposition, but such is not the case in this region. The Sierra bajada has been undergoing dissection rather than gaining by deposition since man began to irrigate the lands, and the streams on the Inyo fans, running only after rains, are not used for irrigating purposes.

[1] For details of precipitation and evaporation in the valley, see *Water Supply and Irrigation Paper, U.S. Geol. Surv., No. 181*, pp. 17–25.

Decrease in volume and consequent decrease in velocity took place on the plains for another reason also. It rained heavily or snow melted rapidly in the mountains, and the mountain streams acquired great volume and velocity. When the rain ceased, or the temperature dropped below 32°, the flood on the plains subsided from lack of supply from above. This undoubtedly furnished conditions under which a large proportion of the material of the fans was deposited.

Glaciation has played a large part in the deposition of the Sierra bajada. Glaciers prepared immense amounts of material in the mountain canyons for transportation by streams. At the same time they furnished great volumes of water to act as the transporting agent during the melting-season. The initial volume and the load being at a maximum, deposition took place on the plains at an unusually rapid rate and to an unusually great extent.

FORMS TAKEN BY THE DEPOSITS

Deposition necessarily took place at the foot of the mountains, at the end of the mountain canyons. The streams flowed on down over the deposit it had made, until it disappeared; hence the fans slope away from the mountains. While the stream was depositing and especially at times when floods were subsiding, channels were filled, distribution took place, new channels were made and filled, and water courses changed constantly. In each new distribution the channels diverged from the mountains. The resulting feature is broader near its edge than near the head; that is, it is roughly fan shaped.

In the Inyo Mountains there is little precipitation, the canyons are far apart and small, and the fans are accordingly too far apart and have grown laterally too short a distance to have been joined. The result is a series of separate fans. In the Sierras, the streams issue at sufficiently small intervals and have built fans of sufficient size, so that they have coalesced to make a compound fan, piedmont alluvial plain, or bajada.

When fans first join, the compound fan is a series of fans, with low places between. If Oak Creek, Shepard Creek, and Hogback Creek are considered as types, there is a tendency for streams to

leave their fans and locate their main channels in the inter-fan depressions. Deposition then takes place in the depression, building it up and making a fan across the edges of two earlier fans. Presumably streams will shift back to their original positions when those positions have become lower than the site of the original depressions, through deposition in the latter. Streams then shift from fans to depressions, make fans there, shift back, build up the old fans, shift again, etc. How frequent and important this may be is not clear. If streams shift freely from higher places to depressions, it is surprising that fans of the bajada stand 200 ft. above the low places between them. The general relief of the bajada should be very slight. The water forming depositing streams probably does not adjust itself freely to the low places, though it is clear that it does so in many cases. The origin of the diverging channels is clear.

THE TRANSPORTATION OF LARGE BOWLDERS

One could hardly travel a mile on the Sierra bajada, or see the heads of the fans at the foot of the Inyo Mountains without asking how the large bowlders came to their present positions. It is essentially a problem of the means of transportation of the largest bowlders farthest from the mountains, for if they can be explained, the smaller bowlders may be considered to have been carried shorter distances by the same methods. Probably the most difficult problems are offered by the largest bowlders, such as those west of Lone Pine, 6 miles from the mountains, measuring $10 \times 20 \times 30$ ft. above ground, and the one at the Cerro Gordo power shanty, larger than the one first mentioned and $1\frac{1}{2}$ miles from the mountains, and several others in that vicinity about as large.

It is clear that these bowlders came to their present positions through the agency of water. Though their size suggests glaciers as the transporting agents, such an explanation is out of the question. The lower limit of glaciation is distinctly marked in the mountain canyons above. The glaciers did not descend to the plains. Nor is there anything in the fact of icebergs floating in a lake. The deposits with which the bowlders are associated are not lacustrine, and no lake existed in the valley during glacial

times. The surface on which the bowlders lie clearly was made by running water. The bowlders are so clearly a part of the fans, and the fans are so clearly running-water deposits, that the bowlders must be considered to have been transported by running water.

It is also clear that the bowlders were not transported according to the common and well-known methods of stream transportation. They have certainly not been rolled along the bottoms of streams in the usual way. They have not the rounded form characteristic of such motion. On the surface of the fans, furthermore, it is impossible for streams to have existed deep enough and strong enough to have so rolled these bowlders. Such streams would have to have a depth about equal to the diameter of the bowlders, be confined in a narrow channel, and flow with a velocity almost inconceivable for a stream. As the bowlders occur on the higher parts of the fans, water of sufficient depth to have carried them would have formed a sheet 20 ft. deep over the fans, and 220 ft. deep over the inter-fan depressions. Even then it would not have been confined to a narrow channel. Also the gradient of the fans is relatively low. Where the largest bowlders are, the slope is not over 6°, and west of Lone Pine not more than 3°. Bowlders much smaller than these are not now being rolled down the mountain canyons above, where the streams are sharply confined and the gradient is very high. The volume of the stream may have been sufficient to carry them *in the canyons* when the glaciers were there. The problem involves transportation *on the fans only.* They were perhaps carried to the heads of the fans by glaciers, glacial waters, and gravity. From there to their present positions, some special methods are called for.

A clue to a possible manner of transportation for these bowlders is obtained from observations of run-off water at the side of a previously dusty road after a heavy rain. Where the running water is but a small fraction of an inch deep, pieces of rock an inch in diameter are carried down stream. The moving of the large pieces involves the transportation of a very much greater amount of fine material. The movement of the large pieces is accomplished by the removal of fine material from the area immediately down stream from, and under, the lower part of the large piece. By undercut-

ting in front, and then by gravity and the push of water and sediment from behind, the large piece is pulled and pushed forward into the depression prepared for it. This process takes place over and over again, the large piece being moved down the low gradient in a halting fashion. The depth of the depression into which the piece falls is never so deep as the diameter of the fragment moved. Once started in motion, the piece is sometimes carried many times its own length by its momentum, and by the force of water and gravity. The motion is usually one of sliding rather than rolling.

It is conceivable that these same methods might operate on the surface of an alluvial fan, on a scale large enough to transport bowlders even 20 ft. in diameter distances of several miles. The bowlder starts from the head of the fan in company with a relatively large amount of fine material. The volume of the stream varies greatly from time to time, with great differences in precipitation in the mountains, and with daily and seasonal ranges in the rate of melting of glaciers. Material is deposited and rehandled time and time again. When the volume is great, fine material is removed from the front of the bowlder and from beneath its front edge, while other material is piled against its upper side, and the bowlder falls, or is pushed, or rolled over into the depression. As the flood subsides, the bowlder may be almost or completely buried, but the next flood uncovers it, and the process is completed. With sufficient time, sufficient variation in volume of water, and sufficient rehandling of material, huge bowlders may thus be transported great distances.

Would the slope of the fans be sufficient for such transportation? In the roadside rill the piece of rock moves a distance several times its own length, while dropping less than its own diameter. Suppose the bowlder 20 ft. in diameter moves 40 ft. horizontally, with a fall of 15 ft.; this would require a gradient of 1,980 ft. per mile. If it moves 60 ft., with a 10-foot drop, the gradient would be 880 ft. per mile. The average slope of the bajada is about 400 ft. per mile. This requires that the bowlder west of Lone Pine, $10\times20\times30$ ft., move about 120 ft., or four times its own length, in dropping 10 ft., or about its own smallest diameter, if the proportions observed hold.

This is conceived to be possible. The process is greatly aided by the momentum obtained by the bowlder when it first moves toward the depression. The depression below the bowlder would not be deep, before the crowding of the material above, and the force of water and gravity would force the bowlder into it. The depression would play out very gradually down slope, giving a constant gradient down which the bowlder could roll, slide, or creep.

Obviously this process would operate to best advantage where there was the greatest volume of water, and where fluctuations of water were greatest; that is, along the main channels of the fans, and on the Sierra fans rather than at the foot of the Inyo Mountains. Bowlders are usually arranged in lines related to the channels, and they are more abundant and larger on the Sierra bajada than at the foot of the Inyos. If this method of transportation of large bowlders is not adequate, methods which are, are not known.

LENS AND POCKET STRATIFICATION

It was shown above (pp. 717–22 and 735–37) that the materials of the fans of the region are but crudely sorted, and that the different textural grades take the forms of lenses and pockets, rather than definite and continuous layers. No textural division was traceable more than 50 ft. in any cut, before it played out in one direction or another. The explanation of this seems clear.

On the surfaces of all the fans in the region are numerous radiating channels and low ridges. In Mazourka Canyon, these channels are braided in almost all directions, though along lines trending generally down valley. These surfaces represent the last deposition on the respective fans. Beneath the present surface there must be many similar surfaces, made and buried as the fan was built.

When flood waters flow over a fan, radiating channels are formed. As the flood subsides, or if the waters are overloaded otherwise, deposition takes place in the channels. The channels are filled with whatever grade of material the stream finds itself unable to carry, and the stream is forced over the side. It then makes a new channel, fills it, and overflows to repeat the process. The fan grows by the addition of long narrow strips of material, sorted

roughly into different textural divisions. These strips diverge from the axis of the fan.

No straight section can be cut in such a deposit without cutting the filled channels. If the cut is longitudinal, practically all the channels will be cut obliquely and at low angles; a few might be cut at right angles. If the fan is dissected by streams cutting down in the old channels, buried channels will still be cut obliquely, as distribution does not take place along lines exactly parallel with previous distributaries.

The filling of a buried channel, when cut along a straight line oblique to the original channel, is exposed as a lens whose length and degree of pinching out depends primarily on the obliquity of the line of cut. A channel filled, buried, and then cut at right angles reveals itself as a pocket in section, the size and shape of which depends on the size and shape of the channel. Continuous layers, uniformly thick can occur only where the depositing distributary was long, straight, and contained uniform material, and where the filling was cut along a straight line exactly parallel to itself. Obviously where exposures are along longitudinal cuts, the result is many lenses, a few pockets, and practically no continuous layers.

That this is the correct explanation of the lenses and pockets of the fans of the region is shown by a correspondence in size between lenses and present surficial channels. On the Sierra bajada, the channels are about 8–10 ft. deep on the average, and the lenses and pockets are about 8–10 ft. thick at their thickest parts. The present flood surface in Mazourka Canyon has a relief of about a foot; the lenses in the older alluvium near by have just about that thickness.

It is understood that any deposit from distributing or anastamosing streams will reveal a lens or pocket structure in straight cuts. The principle probably applies to all alluvial fans, piedmont alluvial plains, flood-plain deposits, glacial valley trains and outwash plains, and deposits on tidal deltas.

THE DISSECTION OF THE SIERRA BAJADA

A variety of events might bear causal relations to the dissection of alluvial fans. Among them are changes in climate, uplift of the

fans, down-warping of their surroundings, etc. Such events and resulting processes may be complex. The cause of dissection in this case, however, seems to be the cessation of glaciation, and the process seems simple.

All the material seen in the bajada, even to the bottoms of the canyons, shows evidence of glacial wear. Before the mountain canyons were glaciated, the fans must have been smaller and lower than now by an amount at least equal to the depths of the canyons. Glaciers were formed, which carved great amounts of material from the heads of the canyons, carried it to their lower ends, and, melting, supplied great quantities of débris-laden waters to flow out over the fan. The fans grew rapidly and became large, out of all proportion to those at the foot of the Inyo Mountains, which were not affected by glaciers.

When the glaciers in the mountains had melted away, these enlarged fans were dissected, for the same reason that a valley train is trenched. The streams now reach the fans with less material than they carried when the glaciers existed, and are able to erode material from the fan.

The matter may be looked at in another way. The pre-glacial fans, being lower than the present ones, had lower gradients and made a sharper break in gradient at the foot of the mountains, and deposition progressed. Now that the fans are higher, their gradients are steeper, and the break in gradient at the foot of the mountains is not so great, and the streams flow out over the fans with their velocities less checked than formerly. This means at least that there will be less deposition on the present fans, and, taken with the fact that the streams have less load, plays a part in the erosion of the fans.

Presumably the canyons will be deepened almost or quite to the bottom of the glacial material. This depth has nowhere been reached as yet.

DEPOSITS OF TWO AGES AT THE FOOT OF THE INYO MOUNTAINS

The older deposit at the foot of the Inyo Mountains is here considered to be a lacustrine deposit, coinciding in age with the lake beds in Waucobi Canyon and those near Haiwee. If this be

correct, the explanation of the dissection of these deposits and the later deposition of fans is not complex.

A lake existed in Owens Valley, probably in Pliocene times, and deposits were laid down in it on the flanks of the mountains. The lake was drained or dried up, and the mountains were probably uplifted. Dissection of the deposits thus exposed and uplifted followed. After erosion had removed a large part of the lacustrine deposit, deposition began at the foot of the mountains, and the present fans have been built up among the remnants of the old lacustrine deposits.

CRITERIA FOR DISTINGUISHING ALLUVIAL FAN MATERIALS

In conclusion we may bring together the distinguishing features of the materials of fans, as seen in this region. The region affords especially good facilities for the drawing of such conclusions, as it contains both running-water and standing-water deposits of similar ages.

Deposits on alluvial fans may be distinguished from those in still water, either lacustrine or marine, as follows:

1. In alluvial fans, coarse material has a wide distribution as against confinement to a narrow zone near shore in standing-water deposits.

2. Textural range in single exposures is large in fan materials.

3. Fan materials are not in general so well sorted as deposits in standing water.

4. The beds and surfaces of fans are likely to have slopes of 6–18°, as against 0–3° in standing-water deposits.

5. Fan materials are likely to have fewer and different fossils than deposits in standing water.

6. Fan material has a lens and pocket stratification, as against a sorting into more or less uniformly thick horizontal layers, as in lakes or seas.

7. Huge bowlders widely distributed vertically and horizontally in a deposit indicate that it was deposited by running water, and with a large proportion of fine material; that is, they indicate that the material is part of an alluvial fan deposit, except in cases where glaciers have affected it, or where standing waters could have

received icebergs, or where basal conglomerates are formed near shore.

8. Theoretically, fan material will be more compact *at first* than still-water deposits of the same textural grade, as each particle drops to the bottom with greater force and the film of water around each particle is not so thick. After water is drained from both deposits, still-water deposits are likely to be more cracked than fan materials, because they contract more. After cementation, still-water deposits, say of clay, will have more veinlets than fan materials of the same texture.

ON CORUNDUM-SYENITE (URALOSE) FROM MONTANA

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Specimens of a corundum-bearing rock from the property of the Bozeman Corundum Company, fourteen miles southwest of Bozeman, Gallatin County, Mont., were obtained for Stanford University by Mr. R. M. Wilke of Palo Alto, Cal. No information concerning the country rock could be obtained except the statements of Pratt in his monograph on corundum:[1] "The corundum seams vary from a few inches to three feet in thickness. . . . . Bozeman: Fourteen miles southwest of this town corundum is found in syenite." From this it would seem that the country rock as a whole is a syenite with bands or seams of the corundum rock. These bands, the writer will show, are corundum-syenite. The rarity of this type of igneous rock accounts for the present paper.

Corundum-syenites have been described only from the Urals,[2] from eastern Ontario,[3] and from the Coimbatore district, India.[4]

The corundum-syenite is a medium to coarse-grained, gray-mottled, more or less banded rock, the banding due principally to the fact that the biotite flakes are mostly in parallel position, though the other minerals are occasionally in rough, parallel position. The gneissoid corundum-syenite, as it may be characterized, is composed of microcline-perthite, biotite, and corundum with subordinate sillimanite, muscovite, zircon, and baddeleyite. The feldspar is for the most part a perthitic intergrowth of microcline and albite, though one slide shows plagioclase, orthoclase, and microcline without any perthite. On a section of the microperthite parallel to {001} the microcline has an extinction angle of $11\frac{1}{2}°$, and the albite, one of $4\frac{1}{2}°$. In this section the albite shows only very faint albite twinning. On a section parallel to {010} the microcline has an extinction of $-3°$ and the albite, one of $+20°$.

[1] *Bull. No. 269, U.S.G.S.*, 133, 144 (1906).

[2] Morozewicz, *Min. u. petr. Mitth.*, XVIII, 217 (1898).

[3] Miller, *Rept. Bureau of Mines*, Toronto, Canada, VIII, Part 8, 210 (1899).

[4] Holland, *Mem. Geol. Surv. of India*, XXX, Part 3, 169 (1901).

The feldspar crystals are sometimes arranged in rough *augen*. The corundum occurs in grayish-blue crystals with an average size of 5 mm. and a maximum size of about 2 cm. The corundum crystals are tabular or prismatic in habit with the common forms: c $\{0001\}$, a $\{11\bar{2}0\}$, r $\{10\bar{1}1\}$, n $\{22\bar{4}3\}$, and θ $\{8{\cdot}8{\cdot}\overline{16}{\cdot}3\}$. The most frequent combination is *acrn*.

The corundum is often surrounded by a zone of feldspar, which is nearly free from biotite. A fibrous mineral occasionally observed proves to be sillimanite as tested in fragments. Muscovite is often observed in thin, cleavable flakes. It does not appear to be an alteration of the corundum. Thin sections show a very small amount of zircon in minute prismatic crystals. The baddeleyite is a black, submetallic mineral which is usually found between the corundum and the feldspar. It occurs in rounded blebs and in prismatic crystals not over 3 mm. in size and usually only about 1 mm. in greatest dimension. The baddeleyite will be described by the author in a forthcoming number of the *American Journal of Science*.

Baddeleyite rather than zircon forms in this type of rock probably on account of the low silica percentage.

A rock sample weighing 243.6 grams was crushed, and after sizing, the constituents were separated by means of Thoulét solution. It was found that good separations could be made by panning with the Thoulét solution. The following shows the amounts of the various minerals and also the percentages by weight, assuming the loss to be equally distributed among the minerals:

	Grams	Percentage
Feldspar	136.6	62.7
Corundum	67.3	30.9
Biotite	12.6	5.8
Baddeleyite	1.1	0.5
Loss	26.0	
Total	243.6	99.9

We may assume the feldspar to be a eutectic of albite and orthoclase. Vogt gives the eutectic ratio for these two minerals as $ab = 58$ per cent, $or = 42$ per cent. We then have 36.4 per cent albite and 26.3 per cent orthoclase. The biotite is the only mineral

which does not have a fixed chemical composition. We may, however, assume the following percentages which are average values for biotite $SiO_2=37$ per cent, $Al_2O_3=16$ per cent, $Fe_2O_3=6$ per cent, $FeO=15$ per cent, $MgO=12$ per cent, $K_2O=10$ per cent, $H_2O=4$ per cent.

The recalculated chemical analysis of the rock given is as follows:

	Orthoclase	Albite	Corundum	Biotite	Baddeleyite	Total
SiO_2	17.0	25.0	....	2.1	...	44.1
Al_2O_3	4.8	7.1	30.9	0.9	...	43.7
Fe_2O_3	....	....	....	0.3	...	0.3
FeO	....	....	....	0.9	...	0.9
MgO	....	....	....	0.7	...	0.7
CaO	....	....	....	...	...	....
Na_2O	....	4.3	....	...	...	4.3
K_2O	4.4	....	....	0.6	...	5.0
H_2O	....	....	....	0.2	...	0.2
ZrO_2	....	....	....	...	0.5	0.5
	26.2	36.4	30.9	5.7	0.5	99.7

Chemically, this is a peculiar rock on account of the high alumina and low silica content. It may be called a corundum-syenite. In order to place this rock in the new quantitative classification it is necessary to convert the percentage compositions of the oxids into percentages of the standard minerals, which in this case are nearly the same as the actual minerals. In other words, the mode and the norm agree closely, biotite being practically the only critical mineral. The calculated norm of the rock is shown in table on p. 751.

All the potash goes into the orthoclase molecule, all the ferric iron and an equivalent amount of the ferrous iron go to make the magnetite molecule. The remaining ferrous oxid goes with all the magnesia to form the hypersthene molecule which requires an equivalent amount of silica. The silica remaining after deducting that required for the orthoclase, hypersthene, and zircon would naturally go into the albite molecule, but it is found that there is too much soda for this amount of silica so that the silica and soda must be distributed between the albite and nephelite according to the equations:[1]

$$x+y=\text{molecules of } Na_2O$$
$$6x+2y=\text{available } SiO_2$$

[1] *Quant. Class. of Igneous Rocks*, 194 (1903).

in which x is the albite molecule and y the nephelite molecule. The remaining alumina goes into the corundum molecule.

	Or	Mt	Hy	Z	Ab	Ne	C
SiO_2 = 44.1	19.1	...	1.7	0.2	22.1	1.0	...
Al_2O_3 = 43.7	5.4	...	...	...	6.3	0.8	31.2
Fe_2O_3 = 0.3	...	0.3	...	...	...	...	...
FeO = 0.9	...	0.1	0.8	...	...	...	...
MgO = 0.7	...	...	0.7	...	...	...	...
Na_2O = 4.3	...	...	...	...	3.8	0.5	...
K_2O = 5.0	5.0	...	...	...	...	...	...
ZrO_2 = 0.5	...	...	...	0.5	...	...	...
	29.5	0.4	3.2	0.7	32.2	2.3	31.2

Orthoclase	= 29.5	F		Salic
Albite	= 32.2	F		Salic
Nephelite	= 2.3	L		Salic
Corundum	= 31.2	C		Salic
Zircon	= 0.7	Z		Salic
Magnetite	= 0.4	M		Femic
Hypersthene	= 3.2	P		Femic
Total	= 99.5			

The classification of the rock according to the new quantitative system is as follows:

$$\frac{\text{Sal}}{\text{Fem}}=\frac{95.9}{3.6}>\frac{7}{1} \quad \text{Class I, Persalone}$$

$$\frac{F+L}{C+Z}=\frac{64.0}{31.9}>\frac{7}{1}<\frac{5}{3} \quad \text{Subclass II, Persalone}$$

$$\frac{L}{F}=\frac{2.3}{62.7}<\frac{1}{7} \quad \text{Order 5, Perfelic}$$

$$\frac{K_2O'+Na_2O'}{CaO'}=\frac{123}{0}>\frac{7}{1} \quad \text{Rang 1, Peralkalic}$$

$$\frac{K_2O'}{Na_2O'}=\frac{54}{69}>\frac{3}{5}<\frac{5}{3} \quad \text{Subrang 3, Sodipotassic}$$

The magmatic name of this subrang is uralose and the magmatic symbol I^2, 5, 1, 3. Only two rocks have previously been assigned[1] to uralose, a corundum-syenite and a corundum-pegmatite, both from the Urals.

[1] Washington, *Professional Paper, U.S.G.S., No. 14,* 217 (1903).

A DRAWING-BOARD WITH REVOLVING DISK FOR STEREOGRAPHIC PROJECTION

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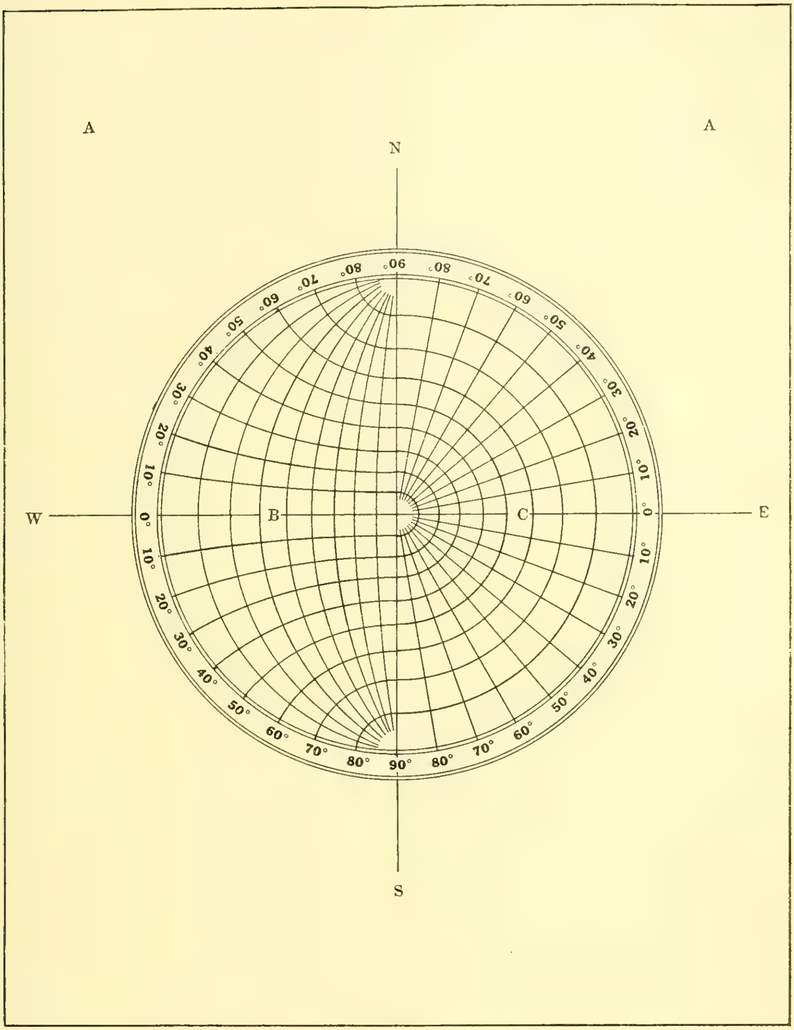
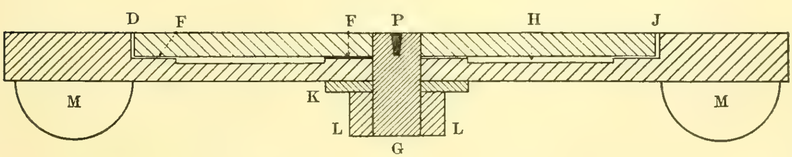
Professor Wülfing recently showed the writer a wall chart for stereographic projection which he has since described.[1] It consists of a ground glass plate back of which is pivoted a 70 cm. Wulff net which is made of pasteboard and projects beyond the glass cover so that it may be turned to any desired position. The advantages of using the Wülfing chart were so apparent that the writer has constructed a drawing-board, for the individual use of students, on a somewhat similar plan but combining with the Wulff net a half-net with the north pole at the center. The construction is simple and the board inexpensive.

In making stereographic projections by ordinary methods, one must either work out his own dimensions, use a Penfield protractor, or a net like that of Fedorow or of Wulff. Transparent nets are an improvement over Penfield's method, although one must always carefully center the net for each measurement. With the drawing-board here described, the net is revolved instead of the paper and no centering is necessary.

The board was constructed from an ordinary drawing-board, $33\frac{1}{2}\times 43\frac{1}{2}$ cm. in size. It was placed on a lathe and a recess, 22 cm. in diameter (D-J in the illustration), was turned out halfway through the board which was 2 cm. thick. A further slight cut (H) was made to reduce friction when the disk is rotated, leaving only the bearing shown at F-F. A 2 cm. hole was turned entirely through the board (P-G). To keep the dial disk (B-C) perfectly flat, it was made from a piece of three-ply, built-up pyrography board, such as is sold in all art stores. This disk, also, was accu-

[1] E. A. Wülfing, "Wandtafeln für stereographische Projektion," *Centralbl. f. Min., Geol., u. Pal.* (1911), 273–75.


A
A
N
W
B
C
E
S
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°


D
F
F
P
H
J
M
K
L
L
G
M

rately turned on the lathe and has a diameter of 21.8 cm., which leaves, when inserted in the recess prepared for it, a very slight margin for expansion. In the exact center a 2 cm. hole was turned and into this the plug P-G was glued. P is a copper rivet set in the top of the plug to serve as a compass center. K is a metal washer and L-L a wooden knob held on the plug G only by friction. This permits its removal in case the dial should ever bind and need trimming down. M-M are knobs, one of which is glued to each corner of the board. They serve as feet to keep the button L from touching when the board is placed on a flat surface. The plug P-G fits snugly into the drawing-board and the dial will readily remain in any position to which it is turned.

The net B-C in the accompanying figure is shown divided only into parts of 10 degrees each. Actually the section B was made by gluing half a Wulff[1] net to the top of the dial disk. The mathematical center is located by a very small pit in the top of the plug P. A further guide to centering the net is a scratch circle described upon the wooden disk and having a diameter of 2 mm. more than the Wulff net. The section C of the dial is used to measure distances on horizontal small circles and vertical great circles. It was made on a sheet of cardboard by drawing circles from the stereographically projected lines of the Wulff net. These also, as well as the projected great circles which appear as radii, are drawn 2 degrees apart although they are shown 10 degrees apart in the figure. Upon the drawing-board itself the N-S and E-W lines were drawn parallel to the sides of the board.

Cutting the net in half occasionally makes it necessary to complete a vertical small circle in two lines. The curves of the right-hand net (C) might have been drawn, say in red, over a complete Wulff net, but the confusion resulting would probably cause more inconvenience than the present necessity of occasionally drawing a vertical small circle in two operations. In most cases where such circles are used, the degree divisions on the equator are a sufficient substitute for the half-net cut off. Perhaps if the lines of every fifth vertical small circle were extended over the upper half of the right-hand net, it would be a convenience.

[1] *Zeitschr. f. Kryst.*, XXXVI (1902), 14–18.

The process of drawing is extremely simple. A sheet of tracing paper is fastened to the board (A-A) by means of thumb tacks and all angles and distances are measured directly by rotating the net into the desired positions. Since in stereographic projections all circles and angles appear in true proportions, such a drawing-board should find extensive use for map drawing as well as for crystal projection.

Reviews

"Middle Cambrian Merostomata." By CHARLES D. WALCOTT. *Cambrian Geology and Paleontology*, II, No. 2.

"Middle Cambrian Holothurians and Medusae." By CHARLES D. WALCOTT. *Ibid.*, No. 3.

"Middle Cambrian Annelids." By CHARLES D. WALCOTT. *Ibid.*, No. 5.

In these three papers Dr. Walcott has described a portion of one of the most remarkable extinct faunas which any paleontologist has ever brought to light. The fossils occur in the Burgess shale of the Stephen formation, in British Columbia. Their manner of preservation is unusual, the organisms being pressed flat, the soft-bodied Holothurians Medusae, and Annelids being represented only by thin films which fortunately are darker than the shale and are usually shiny. The internal structures are often preserved in glistening, silvery surfaces, even to the fine details. The illustrations of the fossils have been beautifully executed by an ingenious process of photography by reflected light, the photographs being reproduced upon heliotype and half-tone plates.

The Merostomata contained in this remarkable fauna are referred to two new genera, Sidneyia and Amiella, both included in the order Eurypterida, and each made the type of a new family. Each genus is represented by a single species. *Sidneyia inexpectans* is a remarkable type, such as might be expected in an Ordovician rather than in a Middle Cambrian fauna, it is much the commoner of the two and some of the specimens are preserved in such a perfect condition that the structural details of the ventral appendages, even of the branchiae, can be worked out. *Amiella ornata* is represented in the collection by a single broken specimen, and is consequently much less perfectly understood.

The commonest of the Holothurians, *Eldonia ludwigi*, a new genus and species, is a peculiar, free-swimming type, with an umbrella-shaped, medusa-like body, growing to a size of 12 cm. in diameter. The spiral alimentary canal, the oral aperture and tentacles, and the water-vascular system are well shown in many of the specimens. Other Holothurians with more or less elongate, cylindrical bodies, having more the form of living members of the class, are represented by the new genera Laggania, Louisella, and Mackenzia. The Medusae are much less

common than the Holothurians; a single new genus and species, *Peytoia nathorsti*, is described, its condition of preservation being identical with that of the Holothurians.

Heretofore the existence of Annelids at the time of deposition of very ancient sediments has been inferred from the presence of certain more or less obscure burrows and trails, but here in the Burgess shale Walcott has been able to recognize eleven genera of these organisms, so perfectly preserved that not only the segmentation of the body but the most delicate appendages can be recognized. The genera are of course all new, and they belong to widely separated families, indicating a remarkable degree of differentiation at this very early period.

Descriptions of the numerous Phyllopod crustaceans which are said to be associated with the organisms discussed in the three papers here noticed, have not yet been published. They will doubtless be made the subject of another paper in this same volume of *Cambrian Geology and Paleontology*. S. W.

Seismic History of the Southern Andes (*Historia sismica de los Andes Meridionales*. Por el Conde Fernando de Montessus de Ballore, director del Servicio Sismólojico de Chile. Primera Parte. Santiago de Chile, 1911).

As is well known, one of the most unstable regions upon the globe is represented by the great Cordilleran backbone of South America. Yet until quite recently little has been undertaken on scientific lines within that vast region, and its seismic history has been a closed book. When, as a consequence of the object-lesson furnished by the late Valparaiso earthquake, the Republic of Chile established a modern seismological service, it very wisely decided to call to its directorship one of the foremost of living authorities upon earthquake phenomena. Already familiar with the Spanish language from years of residence in Central America, and an experienced compiler of seismic maps and catalogues, it was inevitable that the Count de Montessus would not long delay in exploiting the rich mine of seismic facts so long buried in local historical documents. This agreeable task the new director has undertaken, and the wealth of the material has proved even greater than was supposed, so that it will fill several volumes. The first of these has just appeared and is entitled "Seismic History of the Southern Andes" (*Historia sismica de los Andes Meridionales*. Por el Conde Fernando de Montessus de Ballore, director del Servicio Sismólojico de Chile. Primera Parte. Santiago de Chile, 1911).

This seismic history covers the period from 1810 to 1905. The second volume, which is now in press, will treat the much more interesting earthquake of southern Peru, Bolivia, and northern Chile. Seismologists will rather generally regret that it was necessary to print the results in the Spanish language.

W. H. H.

"The Production of Phosphate Rock in 1910." By F. B. VAN HORN. Advance chapter from *Mineral Resources of the United States* for 1910, U.S. Geol. Survey, Washington, 1911.

The total production of phosphate rock in 1910 showed an increase of a little over 10 per cent over the 1909 production. The increase came notably from Florida, with small increase from Tennessee and the western fields, and a drop in production from North Carolina. A drop of fifty-one cents per ton in the average price brought the increase in value down to a little over 1 per cent. Florida is as before by far the largest producer, giving 77.9 per cent of the total for 1910. A short chapter on methods of mining phosphate rock in the various fields is inserted.

A. D. B.

"The Manufacture of Coke in 1910." By EDWARD W. PARKER. Advance chapter from *Mineral Resources of the United States* for 1910, U.S. Geol. Survey, Washington, 1911.

The coke output of the United States in 1910 broke the record of 1907 by nearly a million tons but by no means reached the 1907 record for value. Compared with 1909 the amount increased 6.1 per cent and the value 10.9 per cent. Illinois rose from fifth to fourth rank owing to the installation of ovens at Joliet by the United States Steel Corporation, but in general the rank of producing states changed little. In 1910, 17.12 per cent of the output was from by-products ovens, against 15.94 per cent in 1909.

In spite of the increased production and higher price of coke, 1910 was not a satisfactory year from the producer's standpoint. The increased value of the coal charged into the ovens more than offset the increase in price of coke. A downward tendency in price held throughout, with the result that before the end of the year some manufacturers were running at a loss.

A. D. B.

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